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THE CYCLE OF EROSION AND THE SUMMIT LEVEL OF THE ALPS

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PART I. PENCK'S ESSAY ON THE SUMMIT LEVEL OF THE ALPS

A leading feature of the Alps.—An essay entitled "Die Gipfelflur der Alpen" by Professor Albrecht Penck[1] is of special interest on several counts. It discusses a striking feature of the most studied mountains in the world; it is written by the most accomplished geological geographer of Europe, whose acquaintance with his field is exceptionally intimate; it proposes several refinements of the cycle of erosion; and it employs deduction to an extent that, while unquestionably helpful, has been decried by certain other German geographers.

The subject under discussion is the relative constancy of altitudes in the higher ridges and peaks of the Alps. If one stands on a main summit, countless other summits rise like waves of the sea with crests of similar heights, in spite of the very dissimilar heights that the summits should have if they still represented the unequal deformational uplifts that the different parts of the range have suffered. Penck himself over thirty years ago explained the similar summit altitudes as marking an "upper limit of denudation," above which a mountain top could endure so short a time under the violent attack of the weather and the active removal of detritus on the over-steep slopes as to be rare occurrence.[2] He now extends his previous discussion, first by a more refined account of Alpine forms, in which he introduces an understanding of the effects of glacial erosion that had not been reached when his earlier article was written, and second by an elaborate deductive analysis of the cycle of erosion for mountains, in which the interaction of upheaval and degradation is more fully considered than has hitherto been done. His analysis is summarized in the following paragraphs, to which my comments are added in parentheses.

The preglacial form of the Alps.—The study of actual Alpine forms leads Penck to the conclusion that, as a rule, even if a typical mountain ridge were restored from its present extremely sharp form as given by glacial erosion to its preglacial form, its crest would have

[1] *Sitzungsber. preuss. Akad.*, XVII (Berlin, 1919), pp. 256–68.

[2] "Über Denudation der Erdoberfläche," *Schr. Ver. Verbr. nat. Kenntn.*, Vol. XXVII (Vienna, 1887), p. 431.

been fairly sharp, its sides would have had fairly uniform slopes of too steep an inclination for the retention of more than a thin sheet of creeping detritus, and its height over the adjacent valley bottoms would have been about half the horizontal distance from them, or a quarter of the distance between them. In other words, the ridge slopes must then have been essentially graded with respect to the principal streams. Under such conditions the degradation of the ridges would have still been in fairly rapid progress, and their altitudes would have been as nearly alike as the valleys between which they rose were equidistant. (This modifies and presumably improves a conclusion that Penck had reached eleven years earlier, when he thought that erosion under the leadership of the ancient glaciers had carved the present very sharp Alpine crests out of maturely rounded preglacial ridges.[1]) It is the origin of the sharp preglacial ridges of similar altitude and rapid degradation that is now sought for, and in this search the deductive analysis of several ideal cycles of mountain erosion is undertaken with the object of discovering at what stage of their progress and under what relations of upheaval and degradation the inferred uniform altitudes of the preglacial Alps can be best accounted for. Although the essay is the work of a geographer, the study as a whole is more largely concerned with conditions and processes of the past than with the forms of the present and hence its character is dominantly geological; and in this respect it is characteristic of German physiography in general.

First ideal cycle: Erosion during prolonged upheaval.—Three ideal cycles are examined. All begin with a mass of deformed structures, previously worn down to a lowland. Structural complications and differences of rock resistance are left out of consideration, presumably to simplify the problem. A broad upheaval

[1] . . . . "aus den reifen Firstformen jähe Grate herausschnitt." This statement is to be found on p. 154 of an admirable summary of the physiography of the lands as resulting from the interaction of deformation and erosion, entitled "Die Erdoberfläche," which makes the third chapter of Scobel's *Geographisches Handbuch*, 5th ed.; Leipzig, 1908. It will be referred to below as Sc., with page numbers. An interesting measure of the progress of rational geography may be had by comparing this chapter of 1908 with the corresponding chapter which Penck contributed to an earlier edition of the same work in 1895.

without marked deformation is assumed: it may be taken to have the form of a very broad dome. In the first ideal cycle, a gradual and long enduring upheaval is postulated. During an early stage, the initially flat interstream upland spaces will suffer little erosion and will consequently for a time gain in altitude about as much as they are upheaved. At the same time the depth of the young valleys, which the streams are rapidly incising beneath the flat uplands, must be less than the measure of upheaval. Hence at this stage both the absolute altitude and the local relief of the region are increasing. But as upheaval continues, and as the deepening valleys are opened by weathering, so that their side slopes will have a fairly uniform declivity, a stage must be reached when the flat uplands will be narrowed to sharp ridge crests (Schneiden), and on the attainment of this stage the altitude of the ridges will be as nearly constant as the valleys are evenly spaced. (This deduction depends on a general principle, according to which the height of a ridge crest above the neighboring valley bottoms will be a simple fraction—about a quarter, according to Penck—of the distance between the valleys, provided that the cliffs and ledges on the ridge sides are obliterated by the upward or retrogressive extension of graded slopes of fairly uniform declivity, from the banks of the streams at the valley bottoms all the way up to the ridge crests. Previous to the attainment of this graded stage, the occurrence of ungraded cliffs and ledges in the ridge sides would allow the ridge crests to have heights independent of the spacing of the valleys. Evidently, therefore, the less perfect the grading of the ridge sides from the streams up to the crests, the less perfect the control of crest height by valley spacing.)

During the continuance of this stage the deepening of the valleys in the rising mass will go on, but not yet fast enough to counterbalance the upheaval which is still in progress. The sharp ridge crests will no longer gain in altitude by the measure of upheaval, but only by that measure minus the rate of valley deepening; hence while crest altitude is now slowly increasing, local relief will remain constant. (In view of the fact that large streams grade their courses sooner than the side slopes of their valleys are graded, it seems necessary to assume that when the

valley sides are graded up to the ridge crests, as they must be if crest height is to be dependent on valley spacing according to the principle above cited, then the streams also must be graded, even though, on account of persistent upheaval, they are constantly degrading their graded courses and are therefore not yet permitted to widen their valley floors in flood plains: but this point is not mentioned in Penck's analysis. If the point be well taken, the postulated rate of upheaval should be conceived as rather moderate, even though it is specified as strong [stark]. It would further seem as if a very special though accidental relation must exist between rate of upheaval, climate, drainage area, and rock resistance, in order that the good-sized streams here considered should maintain a graded flow, and that their valleys should maintain graded slopes, even while upheaval is in progress. For it must be remembered that as the streams are not yet deepening their valleys as fast as the mountain mass is rising, their fall must be increasing; and with increasing fall, their graded condition might be lost. Besides, with increase of mountain height, there must be increase of rainfall and of stream volume; and increase of stream volume would still further promote a return to a youthful, non-graded condition rather than a persistence in a mature or graded condition. On the other hand, the increase in valley depth and the accompanying increase in the area of wasting valley sides—part of this second increase being due to the development of many side ravines—will cause an increase in the detrital load that is to be swept away by the streams; and this may permit them to develop graded courses in spite of their increased fall; but none of these details are mentioned in Penck's deductive analysis. In order to avoid misunderstanding, let it be explicitly stated that the introductory clause of this parenthical note does not apply to the small headwater streams of an uplifted peneplain; they deepen the valley heads so slowly that their side slopes are kept graded while the deepening is in progress.[1] It is only the larger streams that grade their beds before the valley sides are graded.)

Balance of upheaval and erosion.—Next comes a stage when the larger streams, which are supposed to be continually invigorated

[1] See my *Erklärende Beschreibung der Landformen* (Leipzig, 1912), p. 259.

by persistent upheaval, are enabled to deepen their valleys as rapidly as the region is upheaved. In this stage (if the valley sides are still kept essentially graded from stream bank to ridge crest), the ridges will be lowered as fast as the valleys are deepened, and both the absolute altitude of the crests, which is then at its maximum, and their local relief will remain constant; and the ridge altitudes will still be as nearly alike as the streams are uniformly spaced. (The deductive analysis which leads to this conclusion is not presented. In its absence, it is difficult to understand how the larger streams can be impelled to more rapid downward erosion than before by the continued and uniform upheaval of the mountain region, without being thrown out of their graded condition and therefore incising rock-walled gorges in the bottom of their previously graded valleys; and in that case the control of ridge-crest height by valley depth must be imperfect. Perhaps a postulate of non-uniform upheaval would lessen this difficulty.)

When upheaval at last ceases, it is supposed that for a time the valleys will still continue to be degraded by downward erosion. In this stage the ridges, in so far as their side slopes are graded with respect to the valley bottoms, will for a time retain sharp crests, and their local relief will remain unchanged although their absolute altitude now begins to decrease. (It is difficult to accept this deduction. If the streams and the ridge slopes were essentially graded during the latest phases of upheaval, the valleys could not be deepened significantly until the detrital load that had to be swept along them by the streams was decreased; and such decrease would not ensue until the ridge slopes were reduced to a gentler declivity than before, and such a reduction of declivity would entail a reduction of ridge-crest relief over valley bottom.) At a still later stage, the land mass remaining stationary, the streams will further diminish their fall and become more perfectly graded. The valley floors will then be opened and widened, the graded slopes of the ridges will be worn to a gentler declivity, and the ridge crests will be rounded. The ridges will then decrease in local relief as well as in absolute altitude. Finally downward erosion ceases, the valleys are still further broadened, the rounded ridges are worn down to broad swells, and the swells are eventually almost obliter-

ated. (It is noteworthy that, in spite of Passarge's dictum as to the futility of deducing the late stages of an erosion cycle under the assumption of unchanging climate—because in his belief climate changes repeatedly during a period so long as a cycle of hard-rock erosion—Penck nevertheless tacitly postulates a uniform climate. It would be better to say regarding the old age of a cycle that downward erosion is more and more retarded than that it ceases, for there must still be some downward erosion as long as the streams have to lower their grades in order to adjust them to the decreasing discharge of waste from the lowering swells. Gilbert has shown that, for a far inland region, such as the plains of central Colorado, not only the valley floors but the whole surface may be lowered hundreds of feet as a result of continued but very slow downward erosion by the streams even after the stage of peneplanation is reached.)

The most significant stage of this ideal cycle is held to be the intermediate one in which the sharp ridge crests maintain a constant absolute altitude as well as a constant relief, in consequence of a balance having been struck between the rate of upheaval and the rate of deepening the larger valleys; but the duration of this stage is shorter than that of the sharpened crests, which persist in the preceding stages while crest altitude is increasing, as well as in the following one while it is decreasing. For these three stages, in which the sharpness of ridge crests is maintained, my term "mature" as originally defined, seems appropriate, in view of the maximum strength and variety of relief then acquired by the mountain mass with its steep but graded slopes; but Penck discards the German equivalent, *reif*, of that term which he had previously used, and speaks in paraphrase, "von einem ausgewachsenen Gebirge mit dem Schneidenstadium der Entwickelung, welches ein Gegenstück zum Schluchtstadium der Täler darstellt, aber von kürzerer Dauer ist." (That the mature stage of sharpened ridges with graded slopes down to the streams should be of shorter duration than the young stage of flat interstream uplands and rock-walled gorges does not seem to be proved.)

Second and third ideal cycles.—In the second ideal cycle, strong upheaval of short duration, and hence of moderate total amount, is

postulated. Here the flat interstream uplands cannot be reduced to sharp crests because they are not lifted high enough to be consumed by the wasting of the valley-side slopes while the slopes are still steep; the uplands are therefore transformed into rounded ridges, and after upheaval ceases the rounded ridges are slowly worn down. Although the sharp-ridge stages of the first ideal cycle are wanting in this second ideal cycle, the earlier and the later stages of both cycles are much alike. In the third ideal cycles, a slow upheaval is postulated: here the valleys are deepened about as fast as the land is raised, they are widened faster than they are deepened, the flat interstream uplands are degraded almost as fast as they are raised, and sharp forms of strong relief are therefore unattainable however long upheaval continues. (It may be here noted that valleys which, either by reason of slow upheaval or of weak rocks, are opened with graded slopes as fast as they are deepened, may be described as "born mature"; also that a region which represents the third ideal cycle may be described as "old from birth." Furthermore, the late stage of Penck's third cycle will be very similar to the late stages not only of his second and first cycles, but also of a cycle of erosion introduced by an upheaval so rapid that little erosion is accomplished while it is taking place. The chief difference between the late stages of these four ideal cycles would seem to be that the streams would be best adjusted to weak structures by the process of river capture in the last mentioned cycle of very rapid upheaval, and least adjusted in Penck's third cycle of very slow uplift; this being for the reason that the more rapid the upheaval, the better the opportunity for large streams to cut down their valleys to a greater depth than that of small-stream valleys.)

Uncertain application of the first ideal cycle to the Alps.—Although no separate examples of mountain forms are adduced in illustration of the second and third ideal cycles, it is pointed out that in a single mountain system, such as the Alps, these two cycles may perhaps find exemplification near the mountain margin, where upheaval was presumably slow and small, and where the ridges are usually rounded. At the same time the first ideal cycle is thought to apply to the center of the Alpine system, where upheaval

has been stronger and greater, and where the mountain crests are sharpest; but the stage of the first cycle to which the preglacial central Alps correspond is not specified. In any event, the initial conditions of the first cycle must be modified before they can represent the case of the Alps by assuming, not an antecedent lowland, but a region of subdued mountain forms, which Penck finds reason to believe had been developed there in an early cycle of erosion before the uplift by which the cycle of preglacial carving was introduced; this early cycle of erosion—or a still earlier one—having destroyed the great inequalities of altitude due to the huge Alpine overthrusts.

It must, however, be a difficult matter to determine whether the conditions of uplift and erosion postulated in Pencks' first ideal cycle really represent those under which the Alps gained their preglacial forms; for apart from the highly specialized relation of unrelated factors which, as pointed out above, is necessary for the persistence of graded streams and of graded ridge slopes during progressive upheaval, there remains the large uncertainty as to whether those parts of the high Alps in which no trace of earlier-cycle forms now survive may not have gained a considerably greater altitude than now at an early stage of the preglacial cycle in virtue of a rapid upheaval—such an upheaval, for example, as that which, acting on a much larger scale, gave the Himalayas their towering heights of today; and also an uncertainty as to whether the rough equality of present Alpine altitudes may not be competently explained chiefly by erosion after upheaval had ceased, as Penck formerly supposed, rather than by a delicate balance of erosion and upheaval as he now suggests. The idea of a constancy of height being imposed on mountain crests by a balance between upheaval and degradation is a beautiful one, and the ingenuity of the analysis by which the idea is carried out is not to be questioned, but its application to Alpine summits does not seem fully assured. As already noted, the region of the Alps was not a lowland at the time preceding the upheaval by which the preglacial cycle was introduced, but as Penck himself shows, a region of subdued mountains. The upheaval was not broadly uniform, as the scheme of the first ideal cycle tacitly assumes, but, as Penck himself again

shows, was significantly greater in certain areas than in others. He indeed suggests that certain longitudinal valleys of today represent belts of smaller and slower upheaval than the areas of lofty and sharp peaks; hence the generalized surface of upheaval, instead of being a single very broad arch from south to north, appears to have been an undulating arch; and, if that were the case, a moderate increase in one of the convexities, as the result of a locally strengthened and accelerated but relatively brief upheaval, might produce the great initial altitudes above suggested. It may be noted in this connection that Sölch, professor of geography at Innsbruck, has recently pointed out certain difficulties that stand in the way of accepting Penck's views.[1]

Let it be added that it is physiographically immaterial to which one of the three sharp-crested stages in Penck's first ideal cycle the preglacial Alps correspond; all three stages would look alike. Similarly, it is physiographically immaterial whether young mountains with flat interstream uplands and subdued mountains with rounded crests are to be explained by his first or his second ideal cycle, which in the early and late stages develop similar forms. Again, it is physiographically immaterial whether old mountains—that is, masses of deformed structure, once lofty but now reduced to undulating lowlands—are to be explained by his first, second, or third ideal cycle, or by a cycle introduced by a very rapid uplift, except in so far as a prevailing adjustment of drainage to weak structures would suggest the operation of a rapid uplift, or of the first instead of the third of Penck's cycles, as noted above.

PART II. THE SCHEME OF THE EROSION CYCLE

Physiographic principles of the erosion cycle.—In order more fully to appreciate the novelty of Penck's discussion, a brief review may be made of the leading physiographic principles that are associated with the scheme of the erosion cycle. One of these principles is that highlands and mountains in existence today are not necessarily the unconsumed residuals of a single primitive upheaval, but that they may be and in many cases are the residuals

[1] "Grundfragen der Landformung in den nordöstlichen Alpen," *Geogr. Annalen*, Vol. IV (Stockholm, 1922), pp. 147–93; see p. 187.

of a renewed upheaval which took place after a more or less complete degradation of the region as prompted by an earlier upheaval. Early recognition of this principle is found in the writings of Ramsay, Powell, and others. Nearly eighty years ago, Ramsay clearly explained the possibility that the hills of South Wales might result from the incision of valleys in an uplifted plain of marine denudation, which had been abraded across a mountainous area of earlier deformation and uplift,[1] and the latest physiographic studies of this region give good reason for thinking that the old master was right, at the same time amplifying his view by showing that the present hill-top levels indicate the occurrence of two plains of marine origin; an inner and higher plain partly consumed by the undercutting of an outer and lower one, the two being separated by a scarp which, although still recognizable, is now like the two plains well dissected.[2]

Twenty years later Powell, when he visited the Rocky Mountains of Colorado in 1867 with a party of students, came upon a similar principle, namely, that the mountains of today may be in a second cycle of erosion after almost complete obliteration of more primitive mountains by subaerial degradation in an earlier cycle; but his only mention of this discovery s in a brief statement published some years later, where it did not attract attention.[3] In the same later volume he first announced an explanation of the Basin ranges which was later very generally accepted, his idea being that before the upheaval of the existing ranges their region was "a comparatively low plain, constituting a general base level of erosion to which that region had been denuded in Mesozoic and early Tertiary time when it was an area of dry land; for I think that from the known facts we may reasonably infer that the Basin ranges, though composed of Paleozoic and Eozoic rocks, are as mountains of very late upheaval.[4] That was a very sagacious utterance for its time.

[1] A. C. Ramsay, "Denudation of South Wales," *Mem. Geol. Surv. Great Britain*, Vol. I (1846), p. 327.

[2] The only published statement of these later studies, made by O. T. Jones, is contained in a rather inaccessible volume: *Souvenir of the Aberystwyth Conference, National Union of Teachers, 1911.* Edited by John Ballinger. Published by the National Union of Teachers, Bolton House, Russell Square, London, 1911.

[3] *Geology of . . . . the Uinta Mountains, Washington* (1876), p. 27.

[4] *Ibid.*, p. 32.

Embodied in the first principle of the cycle—that the erosion of the earth's surface has been accomplished in successive intervals of time marked off by movements of upheaval—is a closely associated second principle to the effect that, during the epochs of rest between the movements, the destructive action of the sea waves on the shore line, or of weather and streams on the entire extent of an uplifted region, may reduce it to a low and nearly featureless surface; a plain of marine abrasion in the one case, a plain of subaerial degradation in the other. An extension of this second principle allows it to include, besides the two just named, other kinds of destructive processes: weather and glaciers, weather and wind (with occasional rain), weather and solution; the latter process finds application particularly in limestone regions and has been worked out chiefly by European observers in the Karst region east of the Adriatic. It may be noted in passing that the reduction of a forest-covered highland to a lowland by the ordinary agencies of subaerial degradation is chiefly accomplished, after the streams have cut their valleys down to grade and after the valley sides have become covered with a sheet of locally weathered soil, by the very slow process of soil creep, attention to which was first directed in this country, as far as I have read, by Lesley in his admirable little book on "Coal and its Topography" (1856).

The most striking illustrations of these two principles are found in regions which, during an earlier cycle of erosion, had reached peneplanation or extensive abrasion, and which are now, after a later uplift of simple character, in so early a stage of renewed dissection as to preserve in their unconsumed uplands little modified remnants of their former lowlands of small relief. Many examples of this kind are now known; indeed a good number of the greater mountain ranges of the world seem to be in a later cycle of erosion than the one introduced by their deformation, and to have suffered far advanced erosion in the cycle preceding the one now current. On the other hand, many other regions show that the movement or deformation by which a later cycle is introduced may interrupt an earlier cycle at any stage of its advance; and also that the interrupting deformation may be of any kind, small or great, simple or complex, slow or rapid, brief or long-enduring. Finally, it

must be understood that while the existence of various slightly dissected plateaus and mountainous highlands proves that in such cases the movement of upheaval was rapid compared to the general processes of subaerial degradation, the occasional occurrence of valleys transecting upheaved masses proves that the antecedent rivers which eroded such valleys were competent to cut down their channels about as fast as the transected mass was upheaved. Hence while an elementary conception of the cycle implies that erosion was chiefly accomplished after upheaval ceased, a more matured conception recognizes that much erosion may take place while upheaval is in progress. The elementary conception may, however, be nearly realized in regions of resistant rocks, quick uplift, and weak destructive agencies; the more elaborate conception may be most fully realized in regions of weak rocks, slow uplift, and strong destructive agencies.

It thus came to be more and more generally recognized that every eroding land area exhibits in its actual form the present stage of a succession of changing forms that began when the area was uplifted and exposed to erosion and that will continue, if no disturbance takes place, until it shall be worn down to a featureless lowland. With the recognition of this succession for actual land areas came its generalization for imagined land areas. Thus concepts of typical cycles of erosion took their place along with concepts of typical rivers, volcanoes, and so on. Progress since then has been made, on the one hand, by inferring past and future changes of many actual land areas, and on the other, by enlarging the number of imagined cycles and elaborating the discussion of their succession of changes.

A third principle of the cycle has been thus established, namely, that a systematic sequence of forms is developed during its progress, the sequence varying according to the structure of the mass that is to be eroded and to the nature of the processes by which the erosion is done. The discussion of each structural unit or entity should, therefore, be carried through separately. The structure of such an entity may be uniform or varied, simple or complex, resistant or weak; the processes of erosion may be, as above noted, weather and rivers, weather and glaciers, weather and wind, weather and

solution (in limestone areas), or weather and waves; and some of these various processes may interact in the same region. This third principle is closely associated with a fourth, namely, that at any stage in the systematic advance of a cycle of erosion, the various elements of form then developed are reasonably associated with one another in a manner appropriate to the structures and processes concerned; and herein lies the chief value of the scheme of the cycle of erosion in the explanatory description of land forms. It advances land physiography from an empirical study of unrelated facts to a rational, evolutionary, genetic study of closely correlated facts. The contributions to the establishment of these two principles have been so numerous that it is impossible to list them here; but one of the earliest and most helpful is to be found in a chapter on the erosion of Alpine valleys in Heim's famous *Untersuchungen über den Mechanismus der Gebirgsbildung*,[1] a work which marked at its time a great advance in the study of the erosional development of valleys during the progress of mountain carving, and which may be appropriately cited here in order, as will be more fully shown below, to measure the great additional advance that has been made in that most difficult and most important of all physiographic problems during the following half century. It may be further noted that my own share in developing the scheme of the erosion cycle has been chiefly in the way of systematizing the ideas brought forward by others.

The terminology of the erosion cycle.—A section may be given to some items of terminology in the scheme of the erosion cycle. The use of the word, cycle, in this connection is my own suggestion. A complete cycle denotes the lapse of time between the initiation of the uplift of a land mass by any kind of deformation and its ultimate degradation. Two ordinary words—interrupt, meaning the closing of a cycle at any stage of its progress by a movement of the land mass, and introduce, meaning the opening of a new cycle by such movement—are not technical terms, but it is convenient to employ them systematically in the sense just indicated. They have been so used above. The disturbance of the progress of a

[1] Vol. I, pp. 293–301, Basel, 1871.

cycle by volcanic eruption or by changes of climate (other than the normal decrease of precipitation and increase of temperature that accompany the degradation of a highland) I have suggested should be called accidents, in order to distinguish them from interruptions due to crustal movements.

The three terms, initial, sequential, and ultimate, referring to the opening, the prosecution, and the ending of a complete cycle of erosion, are due to Gulliver. The application of words taken from the organic cycle of life to indicate stages in the inorganic cycle of erosion was first made—not poetically, but physiographically—as far as I know, by Chamberlin and Salisbury in 1885, when they described a district with narrow valleys as young, and one with open valleys as old;[1] I modified this suggestion by calling a district with open valleys mature, and reserving old for a district in which the inter-valley hills have been almost worn away; but always with the understanding that these organic terms should serve only to suggest, in the briefest possible manner, the general surface features of a structural entity: they must be supplemented by many details in a full description. Even when their application is limited to a structural entity, it is important to recognize that its weaker rocks are more rapidly eroded than its stronger rocks, and hence that belts of weak strata may already be old when belts of resistant rocks are only mature, as is repeatedly the case in the Pennsylvania Alleghenies.

One of my later proposals was that an almost worn-down surface should be called a peneplain; that new word being invented in order to avoid the term, plain of erosion, which excited opposition as demanding too long a stationary condition of the earth's crust for its production. Conoplain has been proposed by Ogilvie to name a surface of subaerial degradation that declines gently in all directions from a central area.[2] Monadnock, following the analogy of meander—the name of a particular serpentine river now commonly used to indicate the curves that similar rivers follow—is

[1] "The Driftless Area of the Upper Mississippi," *Sixth Ann. Rept. U.S. Geol. Surv.*, pp. 205–322.

[2] *Amer. Geol.*, Vol. XXXVI (1905).

the name of a particular residual mountain that has come to be used for such mountains in general.

It may be added that young, mature, and old seem to be best used in connection with features that persist, but with appropriate changes, all through a cycle, such as forms of relief, rivers, and shore lines; and not with features of shorter endurance, like lakes and waterfalls, which are characteristic only of a part of a cycle.

As to terms for rivers and valleys, "antecedent," "consequent," and "superimposed" are due to Powell; the last was shortened to "superposed" by McGee. "Subsequent," which Jukes used in a descriptive sense, I have used similarly in a restricted and technical sense for streams that have grown headward by retrogressive erosion along belts of weak structure, and also for streams which, having been thus developed in one cycle, persist in the same courses in a following cycle. It may be noted that, while consequent rivers and valleys commonly exhibit a bilateral symmetry, subsequent rivers and valleys as commonly do not; also that subsequent streams are very commonly found in pairs on opposite sides of a consequent stream, thus constituting characteristic elements of its bilateral symmetry. McGee's "autogenetic" I have replaced by "insequent," in order to bring it into the sequential group of terms, to which I later added "obsequent" and "resequent."

It is worth noting that the terms of the sequential series may be used for other features than streams and valleys. Thus an anticlinal arch may be called a consequent ridge as long as it retains its axial eminence. When it is breached along the axis by the excavation of weak strata underlying a hard cover, so that the initially single crest is divided by a subsequent anticlinal valley into two lateral crests, they may be called subsequent ridges; their outer slopes are still consequent slopes; their inner slopes are obsequent slopes. If the continuation of erosion reveals along the axis of the breached anticline another anticlinal arch of hard strata, it will gain relief as the first-developed anticlinal subsequent valley is divided into two lateral or monoclinal subsequent valleys; the anticlinal ridge between them is then a resequent ridge. The Appalachian mountains of Pennsylvania and Virginia give abundant

examples of these various kinds of forms. Consequent, obsequent, and resequent may also be advantageously used in the explanatory description of scarps on faulted structures, with particular relation to later cycles of erosion than the one introduced by the faulting.[1] The failure to distinguish between consequent fault scarps and resequent or obsequent fault-line scarps has sometimes led to errors as serious as those resulting from the failure to recognize subsequent valleys as constituting a class by themselves, altogether unlike in origin to antecedent, consequent, and superimposed valleys. It is significant that Powell's terms, anaclinal, cataclinal, etc., which he invented to express empirical relations between streams and structures, have been little used as compared to the terms of the sequential series.[2] A preference is thus implied for terms that express genetic relations.

The term grade, used to describe the smoothed courses of mature and old streams that are neither wearing down nor building up their beds, is due to an oral suggestion by Gilbert. It stands nicely between the long familiar term, degrade, and Salisbury's newer term, aggrade; and it may be as well applied to sheets of waste on soil-covered hill sides, as to streams of water in smooth valley bottoms. The same term also serves properly in connection

[1] "Nomenclature of Surface Forms on Faulted Structures," *Bull. Geol. Soc. Amer.*, Vol. XXIV (1913), pp. 187–216.

[2] A number of elaborate explanatory terms have been suggested without reaching general acceptance. Löwl's terms, symptygmatisch, bikataklastisch, pseudotektonisch, etc., for the descriptions of valleys (*Ueber Talbidung*, Prague, 1884) have not come into use. Penck's terms, homogenetisch and homoplastisch, for forms of similar origin and of similar shape ("Die Geomorphologie als genetische wissenschaft," *Ber. 6ten Internat. Geogr. Kongr.*, London, 1895), are rarely encountered. Passarge's mono dynamische and polydynamische Einzelformen ("Physiologische Morphologie," *Mitt. Geogr. Ges.*, Vol. XXVI, Hamburg, 1912) and Falconer's exogenetic positive or negative forms and endogenetic negative tangential fracture landscape forms ("Land Forms and Landscapes," *Scot. Geogr. Mag.*, Vol. XXXI, 1915; see pp. 394–401) are seldom if ever quoted by others than their authors. Among my own proposals that have not been later used even by myself are compound, complex, and composite, as names for rivers of different origins ("Rivers and Valleys of Pennsylvania," *Nat. Geogr. Mag.*, Vol. I [1889], 183–253; see p. 219). Whether morvan ("Relation of Geography to Geology," *Bull. Geol. Soc. Amer.*, Vol. XXIII [1912], pp. 93–124; see pp. 112–18; also: "A Geographical Pilgrimage from Ireland to Italy," *Ann. Assoc. Amer. Geogrs.*, II [1913], pp. 73–100; see pp. 89–92.) will share a similar fate, or whether it will be adopted like monadnock remains to be seen.

with mature and old shoreline features; but here, as the action of waves is essentially in a horizontal plane, degrade and aggrade should be replaced by retrograde and prograde. The various river terms may be modified by such adjectives as revived or rejuvenated —Heim long ago used the word "Neubelebung"—to suggest idea that a recent upheaval has brought about a youthful stage in a current cycle after a more advanced stage in a previous cycle. Philippson introduced the important idea that revival of stream erosion in the upper part of a river system may be brought about as well by a down-flexing or down-faulting of the lower part of the system as by a general uplift, for thereby the headwaters will be enabled to incise their former valley floors.

Philippson also developed the idea of migrating divides, and the resulting rearrangement of water courses, as in the case of a higher-level stream that is tapped by the headward growth of a lower-level stream at what I have called the "elbow of capture" and thus divided into two parts, the upper part being diverted and the lower part beheaded. As the lower-level stream head approaches the elbow of capture, the divide between them creeps toward the higher-level stream; at the time of capture the divide leaps around the basin of the diverted stream; then as a rule, again creeping slowly, it still further beheads the beheaded stream: a short stream is thus developed between the retreating head of the beheaded stream and the neighborhood of the elbow of capture; as it flows in a back-handed direction it may be called an inverted stream.

Captures of this kind are largely the work of subsequent streams: they may be described as eventual, imminent, recent, and long-past or remote. As they are accomplished, a drainage system departs more and more from its initial consequent pattern and becomes more and more fitted or adjusted to belts of weak structure, and at the same time the surviving ridges and divides become adjusted to belts of resistant structure. The reduced volume of a beheaded stream cannot develop meanders of the same size as those which it followed, with larger volume, before its beheading and by which its valley may have been given an incised meandering pattern; hence, as the reduced meanders are too small to fit their valley curves, they may be called underfit. Conversely, the capturing stream, being

rapidly much increased in volume at the time of capture, may for a time be overfit in relation to its valley pattern. It is believed that underfit rivers may also result from climatic change, as well as from a reduction of stream volume (during unchanged climate) by loss of surface water to underflow in the flood-plain deposits of mature valleys, according to what I have called Lehmann's principle, after its discoverer.[1] Streams that, by reason of uplift, have lengthened their courses across an emerged sea floor, were called extended by Tarr; if extended streams, formerly separate, are led to join in a single trunk, I have called them engrafted; if the branches of a trunk river are separated by the submergence of their main valley, they may be called betrunked or dismembered.

It is manifest that many of these terms may be used in any rational method of physiographic description, but they are peculiarly helpful in the explanatory method based on the scheme of the erosion cycle because the features that they designate are so closely related to one or another of its successive stages. Thus, while consequent streams are defined by the initial slopes of a land surface, and are as a result established at the beginning of a cycle, subsequent streams are not well developed till a mature stage is reached, and obsequent and resequent streams are of later development than subsequents. Similarly, grade is a condition that characterizes the stages of maturity and old age; river captures, especially the captures of consequent headwaters by growing subsequent streams, occur chiefly in the stage of maturity. The adjustment of streams and ridges to belts of weak and resistant structures is also a characteristic of the mature and later stages; and so on.

Gradual development of the cycle scheme.—A correspondent has called my attention to an aphorism of Hegel's, to the effect that a new truth has a short period of victory between an earlier time when it is opposed as a heresy and a later time when it is passed by as a commonplace. Such is truly the case with the general principle that subaerial degradation may in time reduce any mountainous highland to a nearly featureless lowland, on which the scheme of

[1] "Meandering Valleys and Underfit Rivers," *Ann. Assoc. Amer. Geogrs.*, Vol. III (1914), pp. 3–28.

the normal cycle of erosion is founded. This principle was regarded as a dangerous extravagance less than forty years ago; it is usually taken as a matter of course today. But as regards cycles of erosion in which various other processes than "normal" erosion by weather and streams are involved, there is still so much to be learned that they have not yet become commonplace matters. They are still in need of fuller discussion; indeed various refinements are undoubtedly still to be made regarding certain aspects of the ordinary cycle of normal erosion; and the gradual advances by which its present development has been reached ought to prove that even this simplest of all the special forms of the cycle scheme has not yet reached the perfection of an infallible finality. Campbell's discussion of the effects of a moderate tilting on the shifting of divides and the rearrangement of stream courses[1] is a good example of the kind of investigation that different elements and possibilities in the normal cycle need. Careful study should still be given to the manner in which differences of climate affect the work of weather and water and the extent to which surface forms are thereby influenced: the good beginning in such a study made by Passarge for cold, temperate-humid, temperate-subhumid, temperate-arid, and torrid zones in the third volume of his *Landschaftskunde* (Hamburg, 1920) would have a larger value if it had not been limited by his rejection of soil-creep on forested slopes as an effective agency of degradation, as I propose to show in a review to be published elsewhere. A somewhat similar study by Sapper, *Geologischer Bau und Landschaftsbild* (Brunswick, 1917), is less satisfactory because no effort was there made to select really comparable land forms—that is, land forms of similar structure and in a similar stage of erosion—from the different zones.

Among the land forms that vary with differences of climate, to which my own attention was directed during a Pacific voyage in 1914, are ridge crests in relatively homogeneous rocks. In temperate climates of moderate rainfall, ridges are usually forest-covered and their crests acquire a well-rounded or convex cross-profile when the valleys between them are well opened; and even

[1] "Drainage Modifications and Their Interpretation," *Jour. Geol.*, Vol. IV (1896), pp. 567–81, 651–78.

in the fine-textured forms of bad lands, the divides are delicately rounded, instead of being acutely sharp, as Gilbert was led to expect they should be in his study of land sculpture by running water and the law of divides.[1] The rounding of such crests appears to be due to soil-creep, as he later showed.[2] But in torrid lands of rapid weathering and heavy rainfall, the ridges that rise between broadly opened valleys are so extraordinarily sharp that, in proportion to their breadth, they realize the knife-edge acuteness which Gilbert believed ought to result from degradation by running water; and the meaning of their sharpness appears to be that, under the extra-heavy rainfall they receive, they really are shaped chiefly by running water rather than by soil-creep, in spite of the rapidity with which soil is there produced. These broad and sharply divided valleys resemble in a surprising degree certain broadly opened and sharply separated troughs of deglaciated mountains, except that their cross-profiles have no "shoulder" between the higher weathered slopes and the lower wall of glacial scouring.

As to the marine cycle, Gulliver's general account of "Shore-line Topography"[3] has been greatly extended in Johnson's *Shore Processes and Shore Line Development* (New York, 1919). An item that characterizes the mature and later stages of this cycle to which attention has seldom been called is the then frequent occurrence of cliffs of decreasing height; that is, cliffs which have been cut back so far that they now stand behind the former summit of a hill or former crest of a ridge, so that the more they are abraded the lower they become, until the valley beyond them is reached. In regard to the cycle of glacial erosion, valiant efforts have been made by various observers in the Alps to detect the effects of successive epochs of decreasing glaciation, not only in form of trough-valleys, but also in the pattern of valley-head cirques. If these efforts prove successful they will give an increasing delicacy to the description of mountain forms. The solution cycle, not formulated until after the normal cycle had become familiar, has greatly facilitated the description of Karst lands.

[1] *Geology of the Henry Mountains, Washington* (1877), p. 122.

[2] "The Convexity of Hilltops," *Jour. Geol.*, Vol. XVII (1909) pp. 344–50.

[3] *Proc. Amer. Acad. Acts and Sci.*, Vol. XXXIV (1899), pp. 149–258.

The arid cycle is least developed; its theoretical aspects have been carried far beyond their confirmation by observation; not that observation in deserts is wanting, but that the observers there have usually failed to test the correctness of the expectations to which the deductive discussion of this special cycle have led.[1] Walther's studies of deserts are as a rule more concerned with the actual processes there at work and the forms that they immediately produce rather than with the place of such processes and forms in the whole sequence of inferred forms that constitutes a complete cycle of arid erosion. Certain phases of the arid cycle have, however, been admirably analyzed with respect to actual features in the desert region of the southwestern United States by Lawson[2] and Bryan.[3] In all its aspects, the scheme of the erosion cycle has grown by degrees, sometimes slowly, sometimes rapidly; and its growth is still going on, partly by the correction, partly by the modification and extension of earlier ideas.

Reception of the scheme of the erosion cycle.—With many of the older physiographers and geologists in the United States today, whose individual development in their science has been contemporaneous with the growth and establishment of the scheme of the cycle of erosion, its use has been an every day affair, and its advance has been a part of their own progress; but they have often made more use of its principles than of its terminology. Among the younger ones, the scheme has been very largely accepted, ready made, from their seniors. But a few reservations are here needed: for example, the term subsequent, defined as above, has been seldom employed, in spite of the very frequent occurrence of subsequent rivers and valleys in regions of deformed strata; it has been replaced by paraphrases. Other terms, such as obsequent and resequent,

[1] Since writing the statement above, a paper by E. Kaiser, of Munich, on "Morphogenetische Ergebnisse auf Reisen während des Krieges in Südwestafrika" (Verh. 20, *Deutschen Geographentages* [Leipzig, 1921], pp. 159–75) has been received, in which it is said that the observed forms of the coastal desert near Lüderitz Bay confirm certain of the deduced forms of the arid cycle (see p. 175).

[2] "The Epigene Profiles of the Desert," *Cal. Univ. Dept. Geol. Bull.*, Vol. IX (1915), pp. 23–48.

[3] "Erosion and Sedimentation in the Papago Country, Arizona," *U.S. Geol. Surv., Bull. 730 B*, 1922.

have been rarely used, apparently because few physiographers care to carry their analyses so far into detail as the use of these terms implies.

In Great Britain the scheme of the erosion cycle has not been actively cultivated, although its leading principles appear to be more or less passively accepted there. In France the principles of the scheme were largely recognized by de la Nöe and de Margerie in their notable work, *Les Formes du Terrain* (Paris, 1888), and the developed scheme was cordially adopted by de Lapparent and given effective publicity in his *Leçons de Géographie physique* (Paris, 1896); it has since then been practically applied in a number of essays, but the devotion of most French geographers to the historical aspects of their science seems to have caused them to give only a secondary attention to physical geography, the scheme of the cycle of erosion included.

In Germany a number of geographers, including Penck,[1] Rühl,[2] and Braun,[3] have accepted the scheme more or less fully, but certain others, especially Hettner[4] and Passarge,[5] have rejected it on various grounds. Some of the objections to it may be noted.

Objections to the scheme of the cycle.—Various objections have been made to the terminology of the scheme. In spite of the not infrequent use of the German word for cycle (Zyklus) in such a phrase as a cycle or course of lectures, in which the conclusion of the last lecture need have no relation to the introduction to the first, the phrase "cycle of erosion" has nevertheless been objected to because the initial form is not returned to in the ultimate form. However, if insistence be made on that point, it may be answered that a good number of cycles do begin and end with very similar forms. Such is the case with plains and plateaus; and also singularly enough

[1] See his chapter in Scobel's *Handbuch*, referred to above.

[2] "Eine neue Methode auf dem Gebiet der Geomorphologie," *Fortschr. naturwiss. Forschung*, VI (1912), pp. 67–130.

[3] *Grundzüge der Physiogeographie*, Leipzig, 1st ed., 1911; 2d ed., 1915–17. This book is a modified translation of my *Physical Geography*.

[4] In addition to various essays in the *Geographische Zeitschrift*, see *Die Oberflächenformen des Festlandes*, Leipzig, 1921.

[5] "Die Grundlagen der Landschaftskunde," *Die Oberflächengestaltung der Erde*, Vol. III, Hamburg, 1919.

with the many second-cycle mountain ranges which are produced by the uplift and dissection of a peneplain that had been worn down on a mountain mass of disordered structure in an earlier cycle.

Objection has also been made by German geographers to the use of the organic terms, young, mature, and old, to represent successive phases of an erosion cycle, because they insist on interpreting them to mean age in time-measure, instead of stage in development. Yet if two geologists, habituated to use young and old as time-measures in relation to geological formations, were walking across country, and one of them said: "See that young oak," and a moment later added: "Look at this old mushroom," neither of them would for a moment imagine the oak to have lived a shorter time than the mushroom. The young oak might, indeed, be hundreds of times longer-lived in time-measure than the old mushroom. Hence if the organic terms are used in their developmental sense, there should be no difficulty in understanding what is meant by them.

One of the most common grounds for objecting to the scheme of the erosion cycle seems to be a general misunderstanding of its object. Several European geographers have misconceived it as a rigid scheme, to which the varied facts of nature must be forced to conform, instead of as an elastic scheme, readily modified to conform to the varied facts of nature. It has been misunderstood as always demanding a rapid or sudden upheaval, so rapid or sudden that practically no erosion could take place until the upheaval was accomplished. Yet slow upheaval movement with accompanying erosion is manifestly as easily postulated as rapid upheaval. Others seem to have supposed the scheme to present final and infallable conclusions; and on discovering an error or omission, they feel that the scheme must be discarded in its entirety. In my own case, at least, the scheme has been a growth, and its growth is by no means completed. Moreover, however many modifications, improvements, and extensions the scheme may now or later receive, it should be remembered that they are all based upon the valid principles of the scheme already established, and that but for the previous establishment of those principles the improvements of the scheme could not be made. Such modifications and extensions

are like strengthened or reset rungs or newly added upper rungs in a physiographic ladder, on the lower rungs of which a good measure of ascent has already been made above the empirical level of the science fifty years ago. It is not to be questioned that various special cycles have yet to be worked out in order to develop form-sequences appropriate to peculiar structures and processes; and it is greatly to be desired that systematic studies of this kind should be combined with the observational studies of trained geographers in regions of unlike climates. And now after this long detour away from the Alps, return may be made there in order to show that Penck's explanation of the similar summit altitudes involves the elaboration of precisely such a special sequence of forms as contributes to the fuller development of the cycle scheme; but his study unfortunately includes an element of destructive criticism to which attention must also be called.

PART III. PENCK'S CRITICISMS OF EARLIER STUDIES

Progress in Alpine physiography.—It is profitable to read in connection with Penck's *Gipfelflur der Alpen* Heim's chapter on the denudation of mountains which, already referred to as published in his *Mechanismus der Gebirgsbildung* half a century ago, marked the farthest advance reached at that time in the most difficult problem of land physiography. It was then tacitly assumed that the present cycle of Alpine erosion had been introduced by the great crushing which produced the greatly deformed Alpine structures; the possibility of successive more or less complete cycles of erosion, introduced by simple uplift and following after an advanced stage of the earlier cycle introduced by the crushing, was not thought of. Nor was the scheme of one-cycle erosion then carried to its legitimate end of peneplanation; if such a possibility was imagined it was probably dismissed as an extravagance. Furthermore, the important share that glacial erosion has taken in the sculpture of the Alps had not then been learned.

Many are the modifications of those early views that have since been accepted. It is now recognized that the Alps are no longer in their first cycle of erosion, but that the present cycle was preceded by another—whether that one was the first need not be

considered here—in which their enormous overthrusts were enormously eroded; and that the present eminence of the Alps is not a residual of their upheaval at the time of lateral compression, but of a much later and more moderate arching—an undulating arching as Penck now interprets it—by a relatively simple uplift. Moreover, the great work of glacial erosion is now fairly well understood and carefully allowed for, the best study of this great problem being in Penck and Brückner's masterly work, "Die Alpen im Eiszeitalter"; and the immediately preglacial forms of the mountains are believed on valid grounds to have been prevailingly sharp-crested ridges. Finally, instead of assuming a single rapid upheaval as having introduced the present cycle of erosion, Penck proposes several alternative postulates regarding the rate and duration of upheaval and examines their consequences, with the result of selecting the postulate of long-continued upheaval at a moderate rate as providing the best counterpart of the movement to which the present Alps owe their elevation, and of ascribing their fairly uniform summit altitudes to a balance between upheaval and erosion.

Whether the deductions from the postulate of long-continued upheaval are accepted as valid or not, the general sequence of forms that is traced out is a beautiful one. First, both the altitude and the relief of the young mountains are increasing, the increase of altitude, but not of relief, being as fast as the upheaval of the mountain mass; then while the ridges are sharpened, their altitude continues to increase, but now a little more slowly than the rate of upheaval, and the relief is held at a constant value; next, continued upheaval being balanced by degradation in full maturity, altitude reaches and is maintained at a constant maximum, while relief stands unchanged; later, upheaval ceases and altitude is slowly decreased, although for a time the ridges are still sharp and their relief is still unchanged; finally, the sharp ridges of the quiescent mass are rounded and lowered, and thus both altitude and relief are decreased to smaller and smaller values as old age is entered upon. There is elegance as well as originality in these deductions.

Extensions and corrections of the erosion cycle.—Evidently the explicit consideration given in the *Gipflur der Alpen* to several ideal cycles of erosion, differing from each other in the rate and the dura-

tion of the upheaval by which they are introduced, is a helpful advance in systematic physiography, but the advance is not so much in the way of a correction of previous discussions as it is in their extension. Penck implies, however, on a number of his pages that his present views are corrections of earlier views. He states, for example (p. 263), that the sharp-crested preglacial Alpine ridges have been developed from pre-existent rounded ridges (dass manche Schneiden aus runden Formen hervorgegangen sind), and that such a sequence stands in opposition to a previously published scheme of a typical cycle of mountain erosion, in which a reversed sequence of forms is presented, the rounded or subdued ridges of late maturity being explained in that scheme as developed from the higher and sharper ridges of early maturity. But no real opposition occurs here, for in the earlier published statement the typical cycle of mountain erosion was supposed to begin after a previous cycle of erosion had reduced a region of deformed structure to a peneplain which, when upheaved, is dissected in such a manner that the sharp ridges of full maturity naturally enough precede the rounded and subdued ridges of later maturity in the same cycle. On the other hand, in the special case of the Alps, the sharp ridges of the preglacial stage of the present cycle were developed, as Penck clearly explains, out of the rounded ridges of an earlier cycle, which was interrupted by upheaval before peneplanation ensued. In other words, the rounded ridges were introduced, ready made, from an earlier cycle, and in that cycle they had presumably had sharp crests before they were rounded; it was in the following cycle that they were again sharpened. In this special case it is just as natural for the sharp preglacial ridges of the present Alpine cycle to have been developed out of the rounded crests of the earlier cycle, as it is for the rounded, late-mature forms of a single typical cycle which begins with an uplifted peneplain to develop out of the sharp forms of early maturity. Furthermore, had the sharp preglacial ridges of the Alps not been made still sharper by glacial erosion but had a normal climate continued instead, the ridges would have probably been somewhat rounded today in preparation for a more complete rounding in the future. Indeed, the development of rounded ridges out of sharp ridges during the progress of a typical cycle is a well

certified procedure, for it is presented as the normal sequence of change not only in my own earlier published statement of such a cycle, which Penck now criticizes, but also in his own exposition of the cycle scheme in his chapter on "Die Erdoberfläche" in the fifth edition of Scobel's *Geographisches Handbuch* (1908) above referred to; he there explained the successive stages of a cycle of erosion, with its organic terms, young, mature, and old and with its sharpened ridges afterward rounded, as a matter of common and generally accepted physiographic knowledge, for which he very properly accepted the responsibility while enjoying the profit, thus making a marked and very advantageous forward step from his treatment of the same chapter in the second edition of 1895. Flat inter-valley uplands, sharp-crested ridges, and rounded or subdued ridges are there described very explicitly as constituting the normal sequence of forms (Sc. 144). Not only so, the first ideal cycle in the "Gipfelflur" essay, in which a lowland of erosion is assumed as the antecedent form, presents the same normal sequence (264). Hence one cannot help wondering why, if it be thought necessary to assert that the special Alpine sequence stands in opposition to an earlier deduced sequence, Penck's own earlier scheme, as well as that of one of his contemporaries, is not instanced. But in reality no such assertion is necessary, because the two sequences do not stand in opposition to each other. The implication of opposition is irrelevant.

Independence of upheaval and erosion.—In certain other respects also Penck's new views are presented as corrections of view previously announced; and in all these cases, as well as one instanced above, the previous views that he selects for correction are mine. This does me entirely too much honor, for the views of mine that he selects for correction are duplicated in the published statements of his own earlier views. Had his earlier views been published merely as quotations from my writings, his present responsibility would have been less; but they were not; they were very properly published as his own views and that being the case, his own earlier statements should receive correction along with mine, if correction is really called for. But as a matter of fact correction is not called for. The views that Penck now announces are merely extensions, not corrections of earlier views that both of us have held.

Directly after his irrelevant statement that the actual sequence of forms in the Alps—rounded ridges converted into sharp-crested ridges—stands in opposition to the sequence that I have given as typical of an erosion cycle, he goes on to say that the scheme of the cycle should be treated, not as involving the action of erosion on an already upheaved mass, as Davis has done, but as involving the action of erosion during upheaval as well as afterward (pp. 263, 264). It is perfectly true that I have frequently presented the scheme of the cycle as if introduced by upheaval and continued by erosion; the reason for such presentation being that it is the simplest way of placing the general idea before beginners; but it is also true that Penck has presented the scheme in the same simple way. One of the first articles, if not the first, in which he recognized the scheme of the "Erosionszyklus," subdivides it into five stages. The first stage is the emergence of a sea bottom in the form of a gently inclined plain; in the second stage, streams incise valleys and subdivide the inclined plain into flats; in the third, the incision of the valleys is continued, their side slopes are washed down, and the flats are thereby narrowed and converted into divides, which under certain conditions may be sharp; in the fourth, valley deepening ceases and the valley floors are widened at the expense of the dividing ridges between them; and in the fifth, the ridges are worn down so low that neighboring valley floors become confluent and a plain represents the final result of the metamorphosis.[1] Not a word is said here about upheaval after the first stage, and no mention is made of valley erosion during that stage. Nine years later Penck again made a brief analysis of the erosion cycle, in which the incision of a valley is as before said to take place upon a slope (of upheaval), but not during the upheaval of the slope; and the strongest erosion is said to be instituted where the greatest surface unevenesses exist, but not during the production of the unevennesses.[2]

Interaction of upheaval and erosion.—We have therefore both presented the scheme in a simple, elementary fashion. But besides

[1] "Die Geomorphologie als genetische Wissenschaft," *Ber. 6ten Internat. Geogr. Kongr.* (1895), pp. 735–47; see p. 736.

[2] "Die Physiographie als Physiogeographie," *Geogr. Zeitschr.*, Vol. XI (1905); see pp. 9, 18.

setting forth the scheme of the cycle in this simple and elementary manner, I have quite as often extended the scheme by presenting it in a more advanced manner, as opened by upheaval and erosion acting together and completed by the continued action of erosion after upheaval ceases. Nevertheless, the interaction of upheaval and erosion has never been presented by myself or by anyone else in the beautiful manner deduced by Penck in his first ideal cycle of the "Gipfelflur" essay; and for that reason his essay should be regarded as marking an extension of the previous treatment of the cycle scheme. In order to justify the opening statement of this paragraph I desire to cite a number of passages from my earlier writings.

My first contribution to the problem of the erosion cycle was in 1884; it was then stated that valleys in their early stages "will be narrow and steep walled in regions of relatively rapid elevation, but broadly open in regions that have risen slowly, and I believe that rate of elevation is thus of greater importance than climatic conditions in giving the canyon form to a valley."[1] The last clause of that statement was introduced to correct what seemed to be a then prevailing misapprehension, namely, the explanation of the narrowness of the Colorado canyon by the aridity of its region, instead of chiefly by the recent elevation of the plateau in which it is incised. In an essay on the "Rivers and Valleys of Pennsylvania,"[2] the successive deformations of the Appalachian belt in that state are described as follows: "The great Permian deformation . . . may have begun at an earlier date, and may have continued into Triassic time, its culmination seems to have been within Permian limits" (p. 193). "During and for a long time after this period of mountain growth, the destructive processes of erosion wasted the land and lowered its surface" (p. 194). The post-Triassic tilting "culminated in Jurassic" time (p. 196); the Tertiary and Quaternary uplifts are merely dated in a general way without specification of rate. In the following pages on the "general conception of the history of a river," it is said: "For the sake of simplicity, let us suppose the land mass, on which an original river

[1] "Geographic Classification, Illustrated by a Study of Plains, Plateaus and Their Derivatives," *Proc. Amer. Assoc. Adv. Sci.*, Vol. XXXIII (1884), pp. 428–32; see p. 429.

[2] *Nat. Geogr. Mag.*, Vol. I (1889), pp. 183–253.

has begun its work, stands perfectly still after its first elevation or deformation" (p. 203), thus perhaps implying rapid elevation; but only for "the sake of simplicity."

In an article on "The Development of Certain English Rivers"[1] the opening of a cycle of erosion was suggested by the words: "Let gradual and intermittent elevation replace depression"; then the establishment of consequent rivers on the slowly emerging sea bottom follows. In a general discussion of "The Geographical Cycle"[2] upheaval without erosion is given first consideration; but after allowing a page to a mere outline of the erosional changes that ensue, it is explained that the outline must be gone over again to fill in details. The first of these is the correction of the too simple assumption of rapid uplift: "It should not be implied . . . . that the forces of uplift or deformation act so rapidly that no destructive changes occur during their operation. . . . . Even during uplift, the streams that gather in the troughs as soon as they are defined do some work, and hence young valleys are already incised when uplift ceases" (p. 487). Then after giving several pages to a fuller account of the erosional changes during an uninterrupted cycle, certain complications are briefly considered, and one of these is that all kinds of upheavals must be considered; "such movements must be imagined as small or great, simple or complex, rare or frequent, gradual or rapid" (p. 499). The manifest reason for not then going on to give detailed discussion of these various kinds of movements is that a good number of pages had already been occupied in explaining a simple uninterrupted cycle introduced by a relatively rapid elevation, and it may be added that such explanation was needed because even that simple scheme was then essentially novel to the readers to whom it was addressed. The complications of the scheme were, therefore, merely mentioned instead of being elaborated.

Complications of the erosion cycle.—"The Complications of the Geographical Cycle" were, however, made the subject of another article a few years later,[3] in which it was said:

[1] *Geogr. Jour.*, Vol. V (1895), pp. 127–46.

[2] *Ibid.*, Vol. XIV (1899), pp. 481–504.

[3] *Proc. Internat. Geogr. Congr.* (Washington, 1904), pp. 150–63.

The elementary presentation of the ideal cycle usually postulates a rapid uplift of a land mass, followed by a prolonged still stand. . . . . The uplift may be of any kind and rate, but the simplest is one of uniform amount and rapid completion. . . . . In my own treatment of the problem, the postulate of rapid uplift is largely a matter of convenience, in order to gain ready entrance to the consideration of sequential processes. . . . . Instead of rapid uplift, gradual uplift may be postulated with equal fairness to the scheme, but with less satisfaction to the student who is then first learning it; for gradual uplift requires the consideration of erosion during uplift. It is, therefore, preferable to speak of rapid uplift in the first presentation of the problem, and afterward to modify this elementary and temporary view by a nearer approach to the probable truth; and this has been for some years past my habitual method in teaching [p. 153].

A brief analysis of a case of slow uplift is then presented:

A special case necessitating explanation by slow uplift may easily be imagined. If an even upland of resistant rocks be interrupted by broadly open valleys, whose gently sloping, evenly graded sides descend to the stream banks, leaving no room for flood plains, it would suggest slow uplift; the absence of the flood plains would show that the streams have not yet ceased deepening their valleys, and the graded valley sides would show that the downward corrosion by the streams had not been so rapid that the relatively slow process of slope grading could not keep pace with it. In such a case there would have been no early stage of dissection in which the streams were inclosed in narrow valleys with steep and rocky walls; the stage of youth would have been elided and that of maturity would have prevailed from the beginning, but with constantly increasing relief as long as uplift continued [p. 154].

The closing statement as to "constantly increasing relief as long as uplift continued" evidently deserves correction and receives it in the second phase of sharp-crested ridges in Penck's first ideal cycle. A following statement: "Examples of this kind must be rare," perhaps needs correction also; but except in the case of weak rocks that remains to be proved. My writings are to my regret deficient in not giving any special attention to the modifications that the scheme of the erosion cycle should receive in the case of weak structures, such as coastal plains with unconsolidated strata.

Definition of the initial surface.—The fact that none of the above brief allusions to cycles of slow initial uplift are accompanied by detailed discussions of the peculiar features that should distinguish such cycles from others of rapid uplift, perhaps gives some color, as far as the publications thus far cited are concerned, to Penck's

criticism that my scheme of the cycle excludes erosion until after upheaval has ceased. There are, however, other and later publications yet to be cited, in which the interaction of upheaval and erosion is fully discussed; but with these publications Penck seems to have been unacquainted, for after making the above criticism he goes on to say that an erosion cycle ought to be conceived as including the sequence of forms from an initial lowland to an ultimate plain of degradation (and hence involving the interaction of erosion and upheaval while upheaval continues, and of erosion alone after upheaval ceases), and that such a cycle ought not to begin, like Davis' cycle, with an initial form of completed deformation, but at the moment when deformation first displaces a preexistent lowland (p. 264). This conception of the cycle is good but it is not new. It has already been realized, as may be seen in various illustrations concerning plateaus, mountains, and valleys in my "Practical Exercises in Physical Geography" (Boston, 1908), and in the chapter on mountains in my *Erklärende Beschreibung der Landformen* (Leipzig, 1912). But before entering upon that aspect of the question, a paragraph may be given to Penck's comment, above, on the definition of the initial surface of a cycle of erosion.

A number of my diagrams and various passages in my writings may, if taken literally and alone, have given the impression that the initial surface of an erosion cycle is a surface in its new attitude after upheaval and deformation are completed; this impression may be gained especially from passages where a rapid upheaval is tacitly postulated; in fact in the first account of the cycle in my "Erklärende Beschreibung" the initial surface (Uroberfläche) is directly defined as the upheaved surface (p. 30). But inasmuch as other passages and diagrams make it clear that some of the erosional work of an erosion cycle takes place during any upheaval and that much takes place during slow upheavals, a reader who apprehends the spirit of the whole rather than the letter of a part of the cycle problem must soon understand that the true initiation of the cycle is at the beginning of upheaval, and hence that the initial surface should be understood to be, as Penck says, the surface then upheaved. If my writings have given rise to a misunderstanding on this point, it should be noted that a similar misunder-

standing of the initial surface as the fully upheaved surface would be gained if certain passages and diagrams in Penck's chapter on "Die Erdoberfläche," above cited, were taken without their context. His diagrams of warped, faulted and doomed structures (Sc. Figs. 72, 73, 81) are drawn with non-eroded surfaces. His text includes a statement concerning an initial surface that is very similar to the one above quoted from my "Erklärende Beschreibung," namely: "If we review the development of valleys, we recognize clearly that their first course is defined by the presence of an original slope, down which the water flows. This slope is the initial form" (Sc. 143). In other passages one reads that lateral compression produces crustal folds having arches and troughs, like those assumed by a cloth when it is pushed from one side (Sc. 134); that a table-like highland is sometimes upheaved between two faults (Sc. 135); that the Black Forest and the Vosges, with the trough of the Rhine between them, are striking examples of the sides of a collapsed arch (Sc. 136); that young fault blocks form plateaus with steep slopes (Sc. 147); that an upheaved peneplain takes the form of a highland (Sc. 176); that a zone of compression runs through its cycle of erosion as soon as the compression ceases (Sc. 176): none of these passages mention erosion as accompanying upheaval. But it would be manifestly unfair to cite such passages without their antidotes; for example, that arched areas of the earth's surface suffer degradation during their arching (Sc. 136); and that as soon as a surface is uplifted erosion begins to destroy it (Sc. 146); and other similar statements. The fact is that so many elements enter into the problem of the erosion cycle that it is difficult to state them intelligibly all at once. It might be well to use two terms: the initial surface would then be defined as the surface at the time when a crustal movement began to introduce a new cycle; and the (potential) deformed surface would be defined as the initial surface in its new altitude after movement had ceased, but without taking account of contemporaneous erosion.

Practical exercises on plateaus and mountains.—The treatment of erosion during upheaval as illustrated in my "Practical Exercises" may now be taken up. The exercises are based on an atlas

of drawings, which are all furnished with scales so that definite measures may be made of altitude of upheaval, depth and breadth of valley erosion, and so on; and the accompanying text sets many questions which lead to explanatory and quantitative answers. The first drawing of a plateau shows it at an altitude of 2,550 feet, with a narrow canyon already eroded across it, 750 feet deep at the background and 1,700 feet deep in the foreground, where it is about 1,900 feet wide at the plateau level. The second drawing shows the plateau 4,200 feet high, and the canyon 2,700 and 3,200 feet deep at background and foreground, and over 5,000 feet wide at the foreground top. In the third drawing the plateau is 4,700 feet high, and the background and foreground depths of the canyon are 3,500 and 4,000 feet, its width at the foreground top being 8,500 feet. The fourth drawing shows the plateau height unchanged, the canyon depths 4,000 and 4,100 feet, with its width at foreground top roughly 15,000 feet, and a flood plain about 1,000 wide in its floor. The corresponding questions bring out clearly the idea of progressive erosion during the uplift, as indicated by the increasing altitude of the plateau and increasing dimensions of the canyon in the first three drawings; and of continued erosion after upheaval has ceased, as indicated by the greater dimensions of the canyon in the fourth drawing than in the third, although the plateau has the same altitude in both. Later stages of erosion on the still-standing mass are pursued in smaller diagrams to eventual peneplanation.

The exercise on mountains opens with a drawing of a faintly undulating lowland. The second drawing shows the greater part of the lowland warped up into an arch which curves around from east-west in the right foreground to south-north in the left background, and has altitudes of from 4,000 feet to 7,000 feet along its crest; the arch is cut across where its height is between 5,000 and 6,000 feet—that is, aside from its lowest summit—by the canyon of an antecedent river; other parts of the arch are well incised by the revived streams of the lowland or by new streams consequent on the slope of the arch; but these valleys occupy less space than the undissected flats and slopes of the upland. The third drawing shows only the east-west part of the arch with its crest now raised

to 7,000 feet, or 3,000 feet higher than before, and with the valleys more deeply incised and more widely opened at the top of their slopes, so that they have reduced most of the inter-valley upland surfaces to sharpened ridges. The fourth drawing, limited to the western or south-north part of the arch, shows the greatly uplifted mass to be completely carved into mountain forms, some of which exceed 10,000 feet in altitude; all the summits that rise along the axis of the vanished arch, as well as all the ridges that radiate from the summits, now have sharp crests, but none of the valleys, not even that of the large antecedent river, have any flood plains. The fifth drawing shows the south-north mountains subdued to rounded forms, the smaller valleys opened to gentler slopes, and the valley of the antecedent river with a flood plain. The sixth represents the east-west part of the curved range reduced to hills of various altitudes, between which even the small-stream valleys have flood plains; and for a seventh stage, reference is made back to the first drawing. The cycle is thus carried from an initial lowland through high mountains to an ultimate lowland, three of the drawings representing the interaction of upheaval and erosion, and three more—or four if the first is counted over as the seventh—representing the continuance of erosion after upheaval has ceased.

Inasmuch as these exercises were planned for use in secondary schools, the lowland which is upheaved to be carved into mountains and then worn down to a lowland again is assumed, for the sake of simplicity, to be composed of massive rocks, and as a result the highly characteristic but somewhat complicated process of the development of subsequent streams at the cost of pre-existent streams, and to the profit of the adjustment of drainage and relief to weak and hard structures, is excluded. The same simplifying assumption is made by Penck in the first ideal cycle of his "Gipfelflur" essay; for although the actual Alps have a good number of subsequent ridges and valleys, and a much larger number of subsequent valley-side ravines which exercise a considerable measure of control upon the altitude of ridge crests by serrating them with subsequent notches, and thus reducing the relief of the intervening subsequent knobs, no mention is made of variations of structure or of the development of subsequent valleys in Penck's analysis of

the ideal cycle. These omissions may be justified on two grounds: first, the essence of the problem under discussion does not demand their inclusion; and second, the presentation of a discussion before a learned Academy, in which all sciences are represented, does demand, if the speaker wishes to be generally understood, that he should simplify his problem to the utmost; for deeply learned as academicians are in their own subjects they must not be expected to know much about the subjects of their colleagues.

The deficiency regarding belts of strong and weak rocks in my exercise on mountains is, however, made up in large measure by later exercises on rivers and valleys, based on a series of eight drawings, the first of which shows a larger and a smaller river crossing a lowland district of inclined hard and soft strata, the course of the rivers being at right angles to the strike of the strata; the second and third show the district progressively upwarped with accompanying erosion; and the others show successive stages of still-stand degradation with an appropriate growth of subsequent streams and capture of different segments of the smaller river by branches of the larger river; the last drawing represents the greater part of the district again reduced to a lowland.

Various opinions may perhaps be held as to the correctness and intelligibility of these drawings and as to the efficiency or teaching-value of the accompanying questions; but the exercises have nevertheless been found worthy of translation into German.[1] From my own perhaps prejudiced point of view, I am inclined to believe that the three elementary exercises above cited, as well as several others that are not here cited, treat a variety of problems more clearly and intelligibly than they are treated in most advanced textbooks. For example, the development of platforms in the walls of canyons eroded in plateaus, where a high-level thin cliff-making stratum retreats more rapidly than a stronger, underlying cliff-maker, as in Plate 9, Figure 3, and Plate 10, Figure 4; the pattern of cliff-rimmed plateau margins as seen in plan, Plate 7, Figures 5, 8, 9; the relation of an antecedent river to the consequent streams of an up-arched mountain belt, as in Plate 12, Figure 2;

[1] W. M. Davis and K. Oestreich, *Praktische Uebungen in Physicher Geographie*, Leipzig, 1918.

the visible forms associated with eventual, imminent, recent, and long-past river captures, as in various drawings of Exercise VII, and especially in Plate 26, Figures 11 and 12. If these figures are compared the figures illustrating corresponding problems in advanced textbooks—for instance, the three block diagrams illustrating river capture, in Figure 130, Volume III, of Passarge's "Landschaftskunde"—the value of elaborated graphic aids in the teaching of land forms will be apparent. But whatever opinion is held on this aspect of the erosion-cycle problem. there cannot be any question that the exercises above cited embody precisely the scheme that Penck recommends, namely, that cycles of erosion are opened by the uplift of a pre-existent surface, that they are continued for a longer or shorter time by the joint operation of upheaval and erosion, and that they are completed after upheaval ceases by the operation of erosion alone, which eventually produces a lowland of degradation. Moreover, the recommended scheme is presented with much greater detail in these exercises of 1908 than it is in the pages on the Erosionzyklus in Penck's chapter on "Die Eroberfläche" in Scobel's *Handbuch* of the same date. The "Gipfelflur" essay might, therefore, be more appropriately regarded as an extension of the author's own brief treatment of the interaction of upheaval and erosion in that chapter than as a correction of my fuller treatment of the problem.

The explanatory description of land forms.—A similar treatment of the interaction of upheaval and erosion is also presented in my *Erklärende Beschreibung der Landformen* (Leipzig, 1912), which embodies the lectures that I gave in the winter semester of 1908–9 at the University of Berlin from Penck's chair, while he was absent as visiting professor at Columbia University. The first explanation of the scheme in this book is limited to the case of normal erosion; it is presented in ideal form and is based on the elementary assumption of rapid uplift; the idea of slow uplift with accompanying erosion is presented more fully later, although a brief statement at the outset says that upheaval may be imagined to be either slow or rapid (p. 30). The chapter in which this ideal scheme is presented is followed by one in which its deduced consequences are confronted with a variety of facts, as a test of its

correctness and completeness; and the scheme is thereby found to be in need of various amendments and additions, among which the possible action of various other destructive forces than those of normal erosion and the possible interruption of the ideal cycle by any kind of deformation at any stage in its progress are emphasized. Another chapter is then given to an elaboration of the ideal scheme, and here a special paragraph is given to erosion during upheaval, which may be translated as follows:

> It is important to remember that the erosional processes by no means wait until upheaval has ceased before they begin their attack upon a land surface. A very significant erosional work can take place while upheaval is slowly progressing. An upheaval can, in fact, go on so slowly as to permit a large river to preserve a graded course and gently sloping valley sides, especially if the upheaved mass is of weak structure. Such a river will, therefore, have no youth, but will, Minerva-like, begin its life with maturity. On the other hand many examples can be adduced in which a highland surface preserves its initial form between the stream-cut valleys so little altered in the early stage of a cycle that we are well justified in believing that upheaval in general is accomplished more rapidly than degradation [pp. 146, 147].

Various other allusions are made to a slow upheaval and accompanying erosion; for example, under coastal plains, it is noted that the rate of their upheaval should be considered, as the amount of dissection during upheaval is thereby determined (p. 207); but this idea is not elaborated. Again in the chapter on the marine cycle, slow changes of level are explicitly but briefly mentioned (pp. 463, 518). The most detailed consideration of the interaction of upheaval and erosion is presented in the chapter on mountains, where several excerpts from the drawings in the above-cited "Practical Exercises" are introduced. Here both a slow and a rapid arching of an initial lowland of generally homogeneous structure is considered; if rapid, the arched surface will be drained chiefly by new consequent streams; if slow, the larger streams may persist in their antecedent courses (pp. 256, 257). It is explained that when the upheaval is only partly accomplished, V-shaped valleys are incised between portions of the upheaved but otherwise little changed initial surface (p. 258), essentially as in the early stage of Penck's first ideal cycle in his "Gipfelflur" essay; when a greater upheaval is accomplished, the deeper incision of the nearly

graded streams permits the flaring sides of their valleys to consume the greater part of the upheaved surface and thus to produce sharp ridges (p. 267), essentially as in a following stage of Penck's ideal cycle; but some small unconsumed remnants of the initial surface may still survive at this time. A fully matured stage is then described as follows:

> A long-continued upheaval has now brought about a still greater altitude and the deep attack of erosion has produced a strong relief. As long as the upheaval is active, even the large rivers must have a torrential flow; they will cut down deeper and deeper, but will be still unable to develop flood plains. So deep have they already cut and so well are the valley sides opened upwards that all the higher parts of the upheaved initial surface have now been consumed. The characteristic features of a maturely dissected mountain range—still under the postulate of almost homogeneous structure—are: . . . . sharp peaks and ridges with numerous little rock outcrops but with the slopes generally covered with creeping detritus. The most notable of these features is the systematic arrangement of the slopes, so that all detrital and water streams from every peak and ridge descend along well prepared converging lines into their valleys [pp. 274, 275].

A following paragraph makes mention of the similar summit altitudes usually observed in maturely dissected mountains, and refers to Penck's principle of a limiting upper level of denudation as its cause.

Here a question of nomenclature arises. According to Penck's latest scheme, sharp-crested mountains are described in his "Gipfelflur" essay by a paraphrase above quoted; it is added that their youthfulness prevents their being characterized, following Davis, as mature. But this correction, like the others already noted, applies quite as much to Penck's own earlier terminology of the erosion cycle as to mine. Sharp-crested mountains are not youthful according to his definition of that stage of erosion in the Scobel *Handbuch:* young mountains are there said clearly to exhibit remnants of the upheaved surface, which may be large enough to deserve the name of plateau (Sc. 147; also Figs. 83,1; 84,1). Hence now to call sharp-crested mountains youthful is quite as much a departure from his own earlier scheme as from mine. Let such a departure be made freely if it seems an improvement on previous pronouncements; but it does not seem appropriate

to refer to the departure only as a modification of someone else's earlier scheme without avowing that it is also a modification of one's own.

The further discussion of mountain carving in my "Erklärende Beschreibung" postulates a cessation of upheaval about the time that the sharp forms of maturity are reached; then follow in due course, under the action of erosion alone, the rounded or subdued forms of late maturity and the worn-down forms of old age. It is the prolongation of upheaval after sharp-crested forms are reached, as postulated in Penck's first ideal cycle, and the development of a stage of balance between upheaval and degradation with a resulting maintenance for a time of a constant summit altitude and a constant relief that constitute real advances in Penck's treatment of the erosion cycle; but not also, as he implies, the discussion of the interaction of upheaval and erosion during the attainment of sharp-crested forms. The advances are surely valuable and interesting, even though, as pointed out above, some of the deductions which they include seem, in the absence of full explanation, somewhat insecure.

Closing remarks.—The composition of the three parts of this article has been attended with mixed feelings. The analysis of Penck's "Gipfelflur" essay in the first part was a pleasant duty in so far as it was concerned with the constructive side of his duty. The general review and summary of the scheme of the erosion cycle in the second part was also an agreeable task, as it brought to mind memories of work and progress in association with many colleagues through forty years of busy life. The correction of Penck's corrections in the third part was a disagreeable necessity. It would not have been undertaken but for his exceptional rank as a geographer and for the high standing of the Academy in whose proceedings his essay is published. On both those grounds it has been deemed desirable to show that his adverse criticisms are much less pertinent to my treatment of the erosion cycle than a reader of his essay would be led to suppose, and that the real value of his essay, which is unquestionably large, lies in the extension of the deductive treatment of the erosion cycle with especial respect to a mature stage in which upheaval and erosion are balanced.

SOME NEW FEATURES IN THE PHYSIOGRAPHY AND GEOLOGY OF GREENLAND

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Inglefield Gulf

I. THE OROGRAPHY OF GREENLAND

Since 1916 I have been occupied with investigations in northwest Greenland. Though my work is still unfinished, I feel impelled, before starting upon a voyage around the north coast of Greenland, to lay before the public some aspects of the geology of Greenland which have recently come to my notice.

During my travels in extreme northern Greenland, partly along the coast and partly across the inland ice cap, I was struck by the fact that the Archean formations had here developed in a manner quite unknown in the south of Greenland. The gneiss everywhere forms low level plains, which toward the north are gradually covered by sediments, and as the surface of the ice cap everywhere in the north of Greenland is remarkably low, the obvious conjecture seems to be that the gneiss plains extend right across the country to the east coast. Having made this supposition, it was only natural that I should direct my attention to the development of the gneiss surface in other parts of Greenland. It soon appeared that no attempt had previously been made to arrive at any complete survey of the surface elevation of Greenland. Whoever has traveled in Greenland knows that Alpine peaks of 2,000 meters alternate with lower rounded hills, and that in some places the surface is so low and level as to form true plains. To get a comprehensive view of this varied topography, I made a relief map of the whole of Greenland on a small map on a scale of 1:400,000, marking in the altitudes in seven colors from green for lowland and red for the highest peaks. The material at my disposal was partly the altitudes marked on the maps, partly topographical descriptions and pictures, and partly my own observations along the west and north coasts.

These I have explored by sledge and motor boat in their entire extent, covering much of the ground several times.

The relief map showed that the gneiss surface reached an altitude of 2,000 meters in the northern parts of the country and also at about 70° N. lat., both on the west and east coasts. The rest of the country showed a varied topography of highly different types, apparently distributed quite irregularly.

I soon felt, however, that my relief map was characterized by too subjective a view; I had colored large areas about which next to nothing was known. A cartographer working exclusively on low ground will perhaps regard a certain area as an upland, whereas the same region will seem low to another cartographer surrounded by high mountains. On the west and north coasts, where the ground was known to me through personal investigation, I could guard against error fairly well, but on the east coast the coloring was doubtful. In other words, I had to rely exclusively upon the figures given on the maps.

If we generalize some small region in Greenland, e.g., a trade settlement, we get, as a rule, the following picture: Off the coast a number of low skerries, a little farther inland hills—a number of peaks which for each locality have nearly all the same elevation. This is practically the case everywhere in the gneiss area, whether it be low and level, or upland with evenly rounded hills, such as were carved out by the action of the inland ice, or rugged peaks formed by the action of local glaciers and weathering after the ice age. Everywhere the numerous almost equally high eminences seem to be the remains of a once level plain, the true surface of the original Greenland, which has subsequently been more or less dissected by erosion. It now became my object to gain some idea of this original peneplain.

On a large map of Greenland I marked all known heights (about 1,200) in their proper places, and projected each figure at right angles to a line parallel with the coast, marking it as an ordinate on the line. Hence for each figure there is a corresponding point at a greater or less distance from the line, according to the altitude of the peak in question. In a locality with many figures the points nearest the line are derived from the skerries, next come some

points of intermediate height from the littoral regions, and finally the numerous almost equal altitudes showing the higher topography. From the distribution of the points it may be ascertained whether a locality is high or low, but we learn nothing about the various erosion forms, such as the rounded formations due to the action of the inland ice or the alpine formations caused by the local glaciers. In nature the latter always seem higher than the former. By connecting the highest points, a fine zigzag line will appear, showing the average elevation of the peaks. In this I succeeded in constructing the two profiles, Figures 1 and 2, for the west and east coast, respectively. These, however, call for a more detailed explanation:

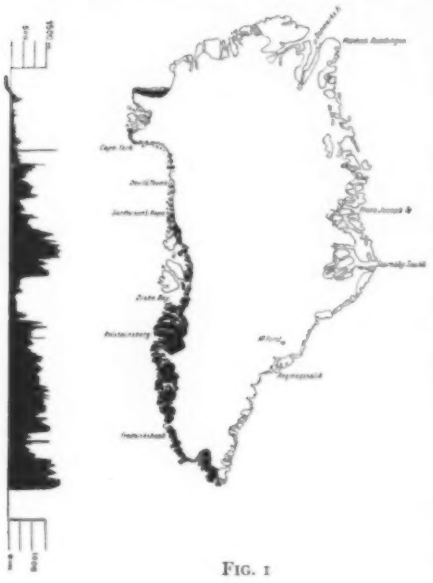

FIG. 1

The west coast profile (Fig. 1).—It will be seen at once that the district of Frederikshaab seems to be remarkably low, a single peak, however, rising to the height of the surrounding areas. This appearance s not due to the district being low in fact, but is caused by the defects of the map, as practically only the skerries are charted. From a ship at some distance from land it is plainly seen that the whole district is high, of the same elevation as the areas to the north and south of it. Moreover, there are a number of peaks near Holsteinsborg which rise above their surroundings and show plainly in the profile. These peaks, however, consist of iron gneiss, they are found only near the coast, and the regions behind them are much lower. Special petrographic conditions have been united to form an isolated high area, which must not be taken into

account when considering the elevation of the otherwise uniform gneiss tracts. The same applies to the isolated peaks in the northern part of the profile. Along the northwestern coast I have ascertained that these isolated peaks did not everywhere consist of gneiss but of later eruptives such as granite, syenite, and diorite (e.g., Sanderson's Hope and Devil's Thumb). Hence, strictly speaking, they should not have been included, but I prefer to differentiate them only from sediments and basalts, as most of the east coast is too little known to discriminate special granite areas.

Apart from the above-named easily explicable irregularities in the west coast profile, it will be seen that the country, from an elevation of about 2,000 meters in the south, slopes gently toward the north, until, slightly to the south of 70° N. lat., it has become quite low. After that it rises again very suddenly to 2,000 meters, only to drop again toward the north until the gneiss surface at about 79° N. lat. is covered entirely by the sea and sediments.

The east coast profile (Fig. 2) is somewhat more intricate. Thus the country suddenly rises to considerable altitudes at Angmagssalik, to drop as suddenly again to low areas. One of the highest peaks of Greenland is found here (Mt. Forel, 2,760 meters), but it is known that the high area only extends a short distance into the inland ice, so that we have here a distinctly high alpine area, well isolated from the surrounding low regions.

There can hardly be any doubt that here we have a tract which, from its peculiar hardness, has resisted erosion, or, more probably perhaps, a horst moving independently of the rest of Greenland. The numerous earthquakes at Angmagssalik favor this conjecture. Some distance to the north of Angmagssalik the gneiss surface has become so low that it is quite covered by basalt. The gneiss appears again in Scoresby Sound, but it is no longer low, the surface lying at a height of about 2,000 meters. With one single interruption to the north of Franz Joseph Fiord, where the inland ice extends to the sediments, we may now trace it up to 82° N. lat., where it has become so low at Nordost Rundingen and at the head of Danmark Fiord that it disappears below the ocean. The northern part of the profile shows some few isolated peaks rising above their surroundings. We know too little as yet to explain the occurrence

of these peaks, but I take it that, as on the northwestern coast, these are more resistant granite areas, which are presumably of later origin than the surrounding gneiss.

The east coast profile, if we do not take into consideration the isolated alpine area at Angmagssalik, thus shows that the gneiss surface from the southernmost point drops toward the level of the

FIG. 2

sea until 70° N. lat., where it rises abruptly to an elevation of 2,000 meters, and then again drops toward the north until at 82° N. lat. it disappears beneath the sea.

The astonishing similarity between the two profiles strikes one at once. Both slope from 60° N. lat. toward 70° N. lat., with a drop of about 2,000 meters; then the country rises abruptly again to 2,000 meters, only to drop again to sea-level at about 80° N. lat.

These facts quite naturally led me to a closer study of the altitudinal conditions of the inland ice cap, in order to ascertain, if possible, an actual connection between the two coastal profiles.

The material from which we can form some idea of the altitudinal conditions of the inland ice is extremely slight. In recent years, however, some journeys have been made across the country, which gain significance in this connection. Farthest south we have Nansen's journey in about 65° N. lat., with 2,700 meters as its greatest height. This is succeeded by De Guervain's journey (about 68° N. lat., 2,500 meters), J. P. Koch's journey (about 75° N. lat., 3,000 meters), Knud Rasmussen's (1) Thule expedition (about 79° N. lat., 2,200 meters), and (2) Thule expedition (about 81° N. lat., 1,200 meters). Peary's journeys in 1892 and 1895 cannot be used for our purpose, as he only states few altitudes in quite general terms. (On his map no heights are given.) One more journey, however, comes into consideration, viz., Nordenskiold's famous expedition in 1870. After Nansen's journey Mohn calculated Nordenskiold's material, and thought he was able to ascertain therefrom that if Nordenskiold had gone straight across the inland ice his greatest height would have been only 2,360 meters. This point would be situated some distance north of De Guervain's route. Hence, looking at the figures at hand, we have from south to north 2,700, 2,500 (2,360) meters south of 70° N. lat., and 3,000, 2,200, 1,200 meters north of 70° N. lat. The figures have been marked in Figure 3, where the two (here somewhat diagrammatic) coastal profiles are seen and the inland ice profile in the middle of Greenland is divided into two halves by a line passing through the highest points of elevation on the inland ice reached on the individual journeys.

As will be seen, there is a distinct depression right across Greenland, a depression which shows itself not only in the altitudinal conditions of the inland ice but also appears plainly in the topography of both the east and west coasts.

II. ALTITUDINAL CONDITIONS OF THE INLAND ICE CAP

The profile of the inland ice cap (Fig. 3) shows that in Greenland there are two centers of glaciation, a large one in the north, and a

smaller one in the south. The line of demarcation between them is formed by the above-noted depression. The recent expeditions

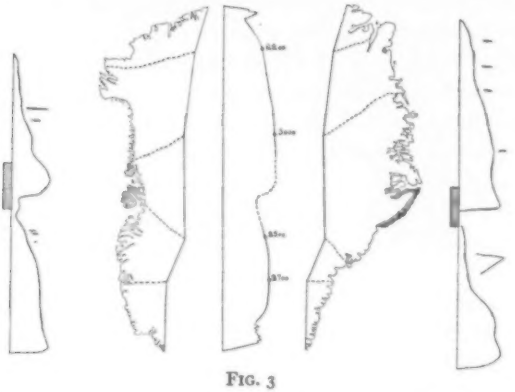

FIG. 3

enable us to mark, roughly, contour lines on the inland ice. This has been attempted in Figure 4, where the proportional heights of the two glacial centers appear very plainly.

FIG. 4

The northern center of glaciation is known from the following expeditions: Peary, 1892 and 1895; Einar Mikkelsen, 1910; Knud Rasmussen, 1912; J. P. Koch, 1913; Knud Rasmussen, 1917. Of these expeditions Koch's is the most important, as it crossed the ice cap very near the place of its greatest elevation. This expedition therefore gives a complete profile of the northern center of glaciation. All the other expeditions took place in the border zone.

The southern limit of the center of glaciation is not known from any expedition, but must presumably be situated slightly to the

north of 70° N. lat. The surface probably inclines pretty much toward the south in this place. Along the west coast high border areas are found in the district of Umanag, Pröven and the southern portion of Upernivik. The surface of the ice cap is high everywhere, in most places about 1,000 meters. From Koch's expedition we know that the 2,000-meter curve is surprisingly close to the coast east of Pröven. In Melville Bay the borderland is low and almost entirely concealed by the ice cap whose margin thus drops to sea-level in this place. From the inmost nunataks it is seen that the 1,000-meter contour is far from the coast.

In extreme northern Greenland the altitudinal conditions are well known on account of the numerous expeditions. Here we can mark the 1,000-meter, 1,500-meter, and 2,000-meter contours with great precision (Fig. 5). It will at once be evident that comparatively large areas of the inland ice cap are below 1,000 meters, and that this contour takes a very irregular course determined by the large fiord glaciers. Especially the Humboldt Glacier and the Petermann Glacier may be traced far into the ice cap. In almost the whole of north Greenland the margin itself is at an altitude of about 500 meters. Einar Mikkelsen's expedition, with its low altitudes, in northeast Greenland, affords good proof that the gneiss surface generally is very low here. To the west of Dronning Louises Land the 2,000-meter contour again approaches land, and everywhere, where it has been possible to get a view of the inland ice from Franz Joseph Fiord and Scoresby Sound its surface has been very high, near 2,000 meters. From Koch's expedition we learn that considerable stretches of the inland ice are above 2,500 meters in northeast Greenland, whereas only a small area is 3,000 meters or upward. The latter area is situated about midway

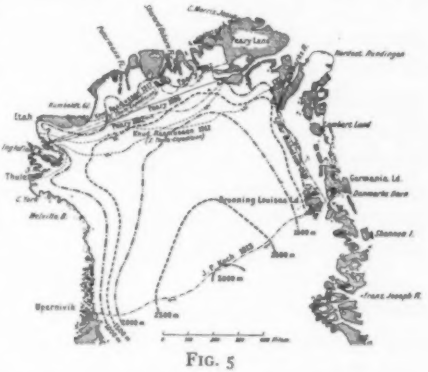

FIG. 5

between the east and west coasts but remarkably far from the north coast.

The marginal zone of the inland ice cap is determined by (1) the substratum, and (2) the climatic conditions. The limit of the marginal zone may, as a rule, be put at the 2,000-meter contour (in extreme northern Greenland perhaps at the 1,500-meter contour) Within this line of demarcation no melting takes place, and only exceptionally do we find traces of inequalities in the foundation.

Our knowledge of the inland ice cap is now so intimate that we may, with fairly close approximation, predict the conditions the traveler will meet with in the marginal zone. From north Greenland especially three types are known:

1. *The littoral region consists of gneiss peaks which speedily change into plateau-like tracts toward the interior.*—The elevation of the ice edge is about 1,500 meters, and the 2,000-meter contour approaches the bordering land. In the months of July and August a narrow melting zone is formed, too narrow to give rise to very considerable streams. After a short journey we reach the 2,000-meter contour and have now entered a level plain of dry and loose snow. Examples are the west coast from 71° to 73° N. lat., and the east coast from 71°to 76° N. lat.

2. *The littoral region consists of fairly low gneiss tracts which extend far into the interior and show a very irregular surface.*—The elevation of the ice edge above sea-level is, as a rule, low. The surface is irregular with nunataks extending far into the ice. There are irregular systems of fissures which prevent the forming of rivers or lakes. The distance to dry firn snow is rather long. Examples of this type are the west coast from Upernavik to Cape York, and the east coast from Germania Land to Nordostrundingen.

3. *The littoral region is formed by gneiss plains or fairly low sedimentary plateaus.*—The elevation of the ice edge above sea-level is about 500 meters. The ice edge is smooth, free from cracks, and easily traversed. Melting occurs in July, and at the close of this month the thin layer of snow had melted about as far as up to the 1,500-meter contour, above which there is dry and loose snow. Near the ice edge there are many small rivers at right angles to it and some few longer rivers and lakes. An example is furnished

by the whole of the north coast from Cape York to Nordostrundingen. Of course there are numerous local deviations from these types.

The southern center of glaciation is known from the following expeditions: Jensen, 1878; Nordenskiold, 1883; Peary, 1886; Nansen, 1888; Garde, 1893; De Quervain, 1909 and 1912. Of these expeditions only two (Nansen, 1888, and De Quervain, 1912) crossed the ice cap; the rest were limited to the border zone on the west coast. Nansen's route cut the center of glaciation near the point of its greatest elevation, and there can hardly be any doubt that this point with its 2,700 meters is about 300 meters lower than the northern center of glaciation. A rather narrow ridge, with an altitude of 2,500 meters and upward, is found from about 62° N. lat. to a point south of 65° N. lat. The 2,000-meter contour everywhere runs near the border of the country. Along the west coast the contour gradually bends inward as it approaches the depression. To the east of Disko Bay great areas of the ice cap are below 2,000 meters. The contour along the corresponding portion of the east coast takes a very irregular course, curving round the high country at Angmagssalik, which forms a small independent center of glaciation. North of this point we are without any knowledge whatever of the inland ice.

The marginal zone shows two types of which the southern one is known from Jensen's, Nansen's, and Garde's expeditions. The borderland consists of high alpine peaks. There are many nunataks, and the edge of the ice cap is high. Locally there are many crevasses and surface moraines. After a comparatively short journey we have passed the 2,000-meter contour and have now entered upon the level dry snow plain. The snow in the marginal zone melts off in June, July, and August. Very considerable streams are not found in the narrow, greatly sloping marginal zone with its numerous fissures.

The second marginal type is found to the east of Disko Bay. The land is well known here from Nordenskiold's, Peary's, and De Quervain's expeditions. The littoral region is low but rather irregular, for which reason the surface of the inland ice is very uneven. The 2,000-meter contour is far inland, which causes a

broad melting zone. Numerous large rivers and many lakes are formed, and locally, crevasses. Beyond the altitudinal conditions the marginal zone shows few similarities to the marginal zone of north Greenland and, on the whole, the conditions are unfavorable to travelers, summer making itself much felt far into the ice cap.

III. THE FORMATION OF ICEBERGS

Now having considered the surface of the inland ice, let us turn to its glaciers and their products, the icebergs.

Sailing northward along the west coast of Greenland, we shall, as a rule, meet the first bergs near Julianshaab. Sometimes they are numerous when derived from the east coast, but they may be scarce or entirely lacking. From Frederikshaab as far as to Egedesminde icebergs are rare. Around Disko, however, they abound in great numbers and from there on they are of common occurrence until Cape York has been passed. Here they suddenly decrease in number, and north of 80° N. lat. they entirely disappear. This circumstance alone shows that the formation of bergs does not take place along the entire edge of the inland ice, and if we look more closely into the case it becomes evident that the greater part of the bergs of west Greenland originate from only a few glaciers but these are exceedingly productive.

Along the entire coast from Julianshaab to Egedesminde the production of bergs is quite insignificant. Almost all the glaciers of the inland ice push down into the head of long narrow fiords and many of the fiords are so shallow at the head that no bergs can be formed. Not until about 69° N. lat. do the bergs occur in any great number, and there we find Greenland's most productive glaciers. The greatest output of bergs no doubt comes from the glacier in the so-called ice fiord at Jacobshavn, but also the Torsukalak and Garajag glaciers are exceedingly productive.[1] From these three glaciers, which are situated within the compass of one and a half degrees of latitude, proceed nearly all the bergs in Disko Bay and Northeast Bay. Only a few are formed along the coast north of the Garajag Glacier. Both Upernivik's and Gieseke's

[1] "The united great glaciers, pouring down to the Karrat Tafiord at 71° 45′ N. lat., are, without doubt, as productive as the Garajag Glacier at the southern corner of Northeast Bay."—Morten P. Porsild.

ice fiords have incorrectly been famed for their numerous bergs. Although a considerable number of bergs occur in summer in the northern part of Sugar Loaf Bay and in Alison Bay east of Amdrup Island, there is no very great output. My investigations in Melville Bay showed that the greater part of the numerous glaciers, which have come down to the sea, only produce few and small bergs. An exception, however, is formed by the King Oscar Glacier in the middle of Melville Bay. It is situated in the very place where the coast bends almost at right angles from south to west, this glacier being thus fed both from the east and the north. Almost all of the numerous bergs, which are nearly always found aground on the many banks and skerries in Melville Bay, come from this glacier.

Few of the numerous glaciers in the Cape York district form bergs, and those that do, only very few. The great Humboldt Glacier, in spite of the great accumulations in its capacious basin, moves very little and forms very few bergs, but here a fresh factor comes into play, viz., the sea ice which hinders the formation of icebergs. That is the reason why, practically speaking, no bergs, or at any rate very few, are produced along the entire north coast from the Humboldt Glacier in the west to Germaine Land on the east coast. Taking this factor as our point of departure, it will be possible to divide all the glaciers of west Greenland into a series of types:

1. *No bergs or very few bergs are formed.*—The glacier rests on land, or if it reaches the sea it moves so little that bergs are only formed at long intervals. Sea ice, if found before the front of the glacier, is not influenced by it, or only very slightly. Nearly all the south Greenland and the majority of the north Greenland glaciers from 71° to 81° N. lat. are examples.

2. *Bergs may break away daily all the year round.*—The glacier comes down to the sea on an open coast where no sea ice is formed in winter so that there is no hindrance to the formation of bergs. Of this type are the glaciers at Cape Alexander, in 78° N. lat.

3. *At intervals of some months bergs are suddenly formed.*—The glacier reaches the sea in a fiord whose mouth is blocked, partly by a submarine moraine and partly by icebergs which have run aground

on it. The water streaming out from under the glacier is dammed up until, the equilibrium being disturbed (most frequently at spring tides), water and bergs are pushed out of the fiord with catastrophic force. Sea ice never prevents the catastrophe. The sole example is the ice fiord at Jacobshavn.[1]

4. *Bergs are formed once a year.*—The front of the glacier is blocked up by sea ice part of the year, so a wall of compressed icebergs is formed in front of, and on, the glacier. In the course of the summer the ice melts off, the bergs often break away with great violence, are shattered, and float away. Porsild has taken the description of the Tormkatak Glacier as the type, but nearly all productive glaciers in west Greenland belong to this type.

5. *Bergs are formed at intervals of a few years.*—In deep bays and fiords of Melville Bay sea ice floats out only in particularly warm or windy summers. The front of the glacier is thus for a brief succession of years blocked up by sea ice so that the bergs accumulate on top of each other, forming an ice conglomerate which freezes into one block after each summer. By degrees a barrier of crowded bergs forms in front of the glacier, and when this barrier of ice conglomerate finally floats off, it may be carried far and wide before it is suddenly scattered into small fragments. In years when there is no ice, more particularly, this kind of berg is very common in the north of Melville Bay.

6. *Bergs are formed at intervals of many years.*—The sea ice remains so long before the front of the glacier that the bergs are fused into a huge ice field with a level surface and without any sharp boundary line toward the glacier at the rear. Toward the perennial sea ice, however, there is still a boundary line. In this way many kilometers of the glacier tongue may float upon the water. The Ryders Glacier in Sherard Osborne Fiord is an example.

7. *Permanent sea ice prevents the formation of bergs.*—On account of the climatic conditions at the inner end of deep fiords, the sea ice as well as the projecting tongue of the glacier increase in height, the annual precipitation finding no outlet. For this reason no

[1] This and the following type have been described by M. P. Porsild in "Om de gronlandske Isfjordes saakaldte Udskydning," *Geografiska Annaler*, Ang. I, Häft 1, Stockholm, 1919.

line of demarcation can be drawn between the sea ice and the glacier. The sea ice in the fiord moves with the glacier almost as far as to the mouth of the fiord, forms fissures, and pushes moraines over projecting headlands or islands in the fiord. If such a fiord is for some reason or other emptied of its ice, numerous floes are formed which may rise from one to several meters above the water. Such floes which, if they are very thick, may thus form actual bergs, are known from Nare's expedition as "Paleocrystic Ice." In the mouth of Robeson Channel they are very common. They are formed in many of the fiords along the north coast of Greenland and Grant Land. The largest Greenland glacier of this kind is the Ostenfeld Glacier in Victoria Fiord.

The glaciers of the east coast have been much less studied than those of the west coast. From Germania Land to, and including, Scoresby Sound, all the glaciers of the inland ice terminate in the heads of deep fiords, and few of them produce bergs in any number worth mentioning. The southern part of the east coast, on the other hand, has several fairly productive glaciers. According to the Eskimos, the largest and most productive glacier is found in Kangerdlugssuag Fiord in 68° N. lat.

It is evident then that icebergs are not formed in extreme northern Greenland. Further it is seen that the bergs along the west coast proceed chiefly from three[1] large glaciers around 70° N. lat. and along the east coast around 68° N. lat.

If we look at Figure 4 we shall see that the productive glaciers both on the east and west coasts are situated exactly at the ends of the great depression across the inland ice. The two centers of glaciation press the ice into the depression which has its outlet chiefly to the west (where there is no basalt under the ice) *through the Jacobshavn, Torsukatak, and Garajag* (Karaiac) *glaciers, and to a somewhat less degree to the east through Kangerdlugssuag.*

IV. THE OROGRAPHIC ELEMENTS OF GREENLAND

The provisional geological survey of Greenland having been ended in 1917, I shall now make an attempt, based on our present knowledge, to divide the country into large orographic elements, an

[1] See footnote 1, page 52.

attempt which will rest more on a geographical than a geological basis (Fig. 6).

By its situation Greenland belongs to America, but it cannot be denied that there are many European features in the geological structure of the country.

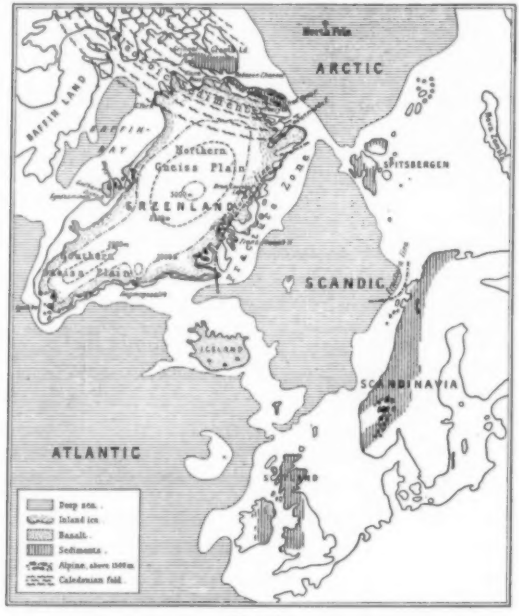

FIG. 6

1. *The southern gneiss area.*—This area comprises the whole of south Greenland to the south of 70° N. lat. The country rock, with some few exceptions, consists of gneiss and granite. As will be seen from the profiles, the surface slopes from south to north. The east coast, however, is, on the whole, somewhat higher than the west coast. The regions round Angmagssalik must be regarded as a separate unit. Morphologically all gradations are found from a pronounced alpine topography in the south to quite low plains in the north. Almost everywhere the rocks consist of a uniform light gneiss (Archean), but in the south numerous batholiths (Algonkian?

and Devonian?) are found. Sediments are found only in a small area in the extreme south. It is the so-called Igaliks sandstone, a reddish unfossiliferous sandstone with many diabasic dikes. It has formerly been classed as Devonian but must now be regarded as somewhat earlier (Cambrian-Ordovician). In the west, and especially in the east, the northern part is covered by basalts.

The gneiss area shows no great fissures or cleavages, but this may be due to defective examination. It seems natural to refer it to the great Canadian shield which, as we know, is distinguished by its great uniformity.

2. *The northern gneiss area.*—This forms the greater part of the northern half of Greenland. On the south the limit is formed by the above-noted depression at 70° N. lat. It is limited on the west by Baffin Bay. Toward the north the gneiss can be traced as far as Kane Basin and to Danmark Fiord on the east coast. Toward the Atlantic there are great fracture lines of which the inmost form the eastern boundary. The surface slopes gently from south to north. There is, however, another dip with an east-west trend. Hence the lowest tracts are found in northwest Greenland. The gneiss is very uniform everywhere; batholiths occur but have not yet been examined. In the Cape York district there seem to have been tectonic disturbances (in the Ordovician?), though to no great extent. In the north great portions of the gneiss surface are covered with sediments. In the east, too, in Dronning Louises Land, there are sediments. This gneiss area, too, is naturally connected with the Canadian shield.

3. *The great Paleozoic transgression in northwest Greenland.*[1]—In the south the sediments may be traced to a line running from Cape York to the head of Danmark Fiord, in the east they reach the Atlantic over a short stretch, on the north they are bounded by a folded chain whose southern boundary runs from a point some distance south of Fr. Hyde Fiord to Polaris Harbor in Robeson Channel. Westward the same strata are found over great portions of the Arctic archipelago, and the transgression has already been known from these parts since the middle of the last century. Everywhere the strata lie almost undisturbed on the gneiss surface, the

[1] Studied and described by the present writer in *Stratigraphy of Northwest Greenland.*

oldest being farthest south, while toward the northwest we meet with later and later formations. Immediately on top of the gneiss is deposited a red or gray sandstone with conglomerates and numerous diabase dikes (Cambrian?). Over this is a light limestone with Gymnosolen, then dark limestone with Maclurea (Ordovician), and above this follow Pentamerus limestone, coral limestone, graptolite shales, and trilobite limestone (Gotlandian), and finally coarse sandstone without fossils. The total thickness of the whole series of strata is more than 2,000 meters.

4. *The north Greenland folded chain.*—The entire north coast of Greenland from Fr. Hyde Fiord to Polaris Harbor consists of folded ranges whose age is determined by the fact that the folding is later than the zone with *Monograptus priodon* and earlier than fossiliferous Devonian which is not, however, very well known yet. The folding is continued westward and seems to disappear gradually in the interior of Grinnell Land. From this place it was first mentioned by Feilden under the name of "Cape Rawson Series." The intensest folding is found in the east in the interior of Peary Land. In continuation of the folding a submarine ridge extends to Spitzbergen. This ridge separates the Atlantic from the Arctic Ocean. In Spitzbergen, as is well known, there are strongly folded strata (Hekla Hook). These strata, according to Swedish geologists, form a continuation of the great Caledonian system which is known from Scandinavia and England. In my treatise,[1] quoted above, I have described more closely the Greenland portion of this folding and shown that it is the western end of the great Caledonian system. This element, then, connecting up toward the east, is a European feature in the structure of Greenland.

5. *The great fracture zone on the northeast coast of Greenland.*—This area which, geologically speaking, belongs to the most varied regions in Greenland, is unfortunately but little known. The trend of the fracture lines has been investigated in its main features in the southern part of this area, but in regard to the northern part we are reduced to mere conjectures. With all reserve I provisionally place the innermost fracture line at the western limit of the Carboniferous in 81° N. lat. Thence the fracture line runs west of Lambert

[1] *Stratigraphy of Northwest Greenland.*

Land down to the eastern side of Dronning Louises Land and thence farther on to Franz Joseph Fiord, in which the innermost fracture line shows very plainly, the gneiss plane appearing in the inmost arms of the fiord. The same applies to Scoresby Sound. The fracture lines seem to be grouped with a slightly concentric course fairly parallel to the coast. Liverpool Land forms a horst of gneiss, but otherwise the fractures descend in steps toward the Atlantic. Fossiliferous strata are known from all geological periods except Cambrian and Permian. The marine fossils, as far as they have been studied, fall into line with corresponding European faunas.

On the eastern side of the Atlantic we know a locality which, in spite of its small extension, is very similar to the east Greenland fracture zone, viz., the Jurassic strata on Andrew near Lofoten. Here, too, the strata are separated by a fracture of very considerable size from the gneiss behind. All in all we can say that the Greenland fracture zone, too, is connected with the Atlantic, and tectonically, as well as stratigraphically and paleontologically, shows points of similarity to European conditions.

6. *Greenland's basalt region.*—It has long been known that both the east Greenland and west Greenland basalt areas were formed in the Tertiary period and they have often been mentioned in connection with the Tertiary basalt strata which form Iceland and the Faroe Isles, and are also represented in Scotland and Ireland. Not only do petrographic and stratigraphic conditions tempt us to regard all these basalt occurrences as belonging together, but in a purely geographical respect, also, they form a unit, since they all, the west Greenland area excepted, lie on a large submarine ridge across the Atlantic.

If we look at a map it will at once be evident that the above-mentioned depression across Greenland is situated exactly in continuation of the great submarine basalt ridge. In Figure 3 I have marked the geographical extension of the basalts in the profiles both on the west and east coasts, and the basalts on both coasts prove to be situated at the exact spot where the low gneiss country is suddenly replaced by 2,000-meter high mountains. It would seem that there is a connection between the depression and

the basalt areas of Greenland. If this be correct, all the basalt occurrences geographically form a unit also.

The basalts have protected some of the sediments against erosion, as for instance the well-known fossiliferous strata of Cretaceous and Tertiary origin in west Greenland and a small area with Tertiary marine fossils on the east coast. The conditions of deposition of the basalts, however, are but little known. On the east coast they appear to have been deposited on the northeastern corner of the southern gneiss plane, no fractures intervening. Exactly similar conditions are found in Disko Bay on the west coast. Here we can trace the southern gneiss plane from the low skerries at Egedesminde northward across some reefs and groups of islands to the skerries at Godhavn and in Disko Fiord, where basalt beds of a thickness of 1,000 meters rest on gneiss. Some of the basalts north of Disko, on the other hand, seem to be divided from the northern gneiss surface by cleavages. The elevation of the basalt plateaus is 1,000 meters at Godhavn. In 70° N. lat. the height is 2,000 meters, and north of this it again decreases. The chief center of eruption of the basalt seems to have been about where Vaigat now is. This element in the structure of Greenland, then, forms the western part of a series of strata which has its greatest extension in the Atlantic.

The American elements, then, are the following: (1) the northern, and (2) the southern gneiss planes, which both form parts of the great Canadian shield, and (3) the Paleozoic sediments, which form the northwestern part of the widely extended series of strata which covers great portions of the Arctic archipelago.

Elements showing relationship on the eastern side, with Europe, are as follows: (1) the Greenland part of the Caledonian folding zone, (2) the fracture zone in east Greenland, and (3) the great basalt area which, besides being extended in the Atlantic, is also found at both ends of the depression across Greenland.

V. THE GREENLAND FIORDS

Few countries contain so many and such large fiords as Greenland and yet many of these fiords are still in part ice filled. Geographically they may be divided into three types:

Of these I shall first consider the large fiords along the north coast of Greenland. Most of them cut right through the Caledonian folds and may be traced far into the country as deep canyons in the sediments and farther on as pronounced depressions far into the inland ice (Fig. 5). The fact that even the folded range has been cut through in numerous places favors the theory that these fiords originated long before the glacial period. Petermann Fiord and Sherard Osborne Fiord are both good types of such sedimentary fiords (Fig. 7).

FIG. 7

FIG. 8

A quite different type of fiords is found in the large ice-free area between Egedesminde and Godhavn. These fiords may suitably be called fracture fiords, having originated by the cleavage of the gneiss along its planes of fracture. The best examples are found in the fiords round Holstensborg. The formation of these fiords has been studied by Karnerup,[1] and it is to be regretted that a work of such genius is only accessible in Danish.

The last type is given in Fig. 8. It is seen that large fiords are chiefly found in three places, viz.: round the south point of Green-

[1] *Meddel. om Gronland*, Bd. II.

land and on both the west and east coasts north of 70° N. lat. Large fiords, in other words, are found exactly where the country is high, and as the country gradually becomes lower the fiords gradually become smaller. It will be seen, however, that even deep fiords suddenly disappear near the edge of the inland ice. The largest fiord complexes of the world, Scoresby Sound, Franz Joseph Fiord, and Northeast Bay, practically speaking, do not influence the surface of the inland ice at all. It must, therefore, be supposed that all these fiords are of very late origin and that the erosion is as yet in only a slightly advanced stage.

VI. THE ORIGIN OF THE DEPRESSION

By means of the altitudes shown on the maps, I have indicated, above, evidences for a depression right across Greenland, and I have then attempted to give a comprehensive view of our present knowledge of the elevation, surface, and iceberg production of the inland ice of Greenland. Further, I have attempted to divide Greenland into large geographical and geological elements, and, finally, I have indicated a division of the Greenland fiords.

All this is grouped about facts which lead to conclusions which anyone with a knowledge of conditions in Greenland may draw for himself. In entering now upon some questions of a more hypothetical kind, it is not without a certain hesitation, as I am by no means blind to the fact that our knowledge of Greenland is as yet too deficient to warrant entering into detail. I shall, however, attempt to point out some of the questions whose solution is reserved for the future, and try to indicate on what lines I believe that some of the questions will be answered—in short, point out some of the main features of some of the numerous geographical and geological questions that are still unsolved in Greenland.

The time of the formation of the depression cannot be stated with certainty. We have an indication in the fact that the basalts seem to be connected with the depression; but to infer from this that it was formed in the Tertiary period would be too hasty a conclusion, since it is conceivable that the depression—this division of Greenland into two parts—may date farther back and may have determined the direction of the great Atlantic basalt fissure. A

continent like Greenland will always be a hindrance to the formation of fissures across the country. It would then be only natural that the fissure would take its course where Greenland, considered as a continent, was weakest.

The theory that the depression is simply a direct continuation of the great Tertiary fissure is, however, the most natural explanation. We know that there have been great movements of the earth's crust in mid-Greenland since the Tertiary period, marine fossiliferous strata having risen several hundred meters since then. If the depression is a Tertiary fissure, the consequence would be that the gneiss planes would be displaced vertically along the fissure about 2,000 meters in relation to each other. It is, however, questionable whether so huge a displacement could take place without the ground on the sides being broken. No such phenomenon is known from Greenland, but that may, of course, be due to defective investigation.

The inclination of the northern gneiss plane toward the north may be explained by the fact that its northern part is heavily weighted with sediments. If a fissure were formed right across the country the gneiss plane which carries the sediments would be reduced to about half and therefore be tilted so that the northern part would be lowered and the southern part raised. In the same way it may be assumed that the northern part of the southern gneiss plane has been submerged beneath the weight of pouring out basalt masses. It has been shown above that both in the west and the east basalt is found deposited on the surface of the southern gneiss plane. Toward the west there are no great quantities left, but escarpments of 1,000 meters show that the basalt once had a greater extension toward the south. Eastward much larger basalt areas now rest on the southern gneiss plane, and how far the basalt here penetrates below the inland ice is still unknown. If we imagine the displacement along the fissure taking place in such a way that the southern edge of the northern gneiss plane was raised just as much as the northern edge of the southern gneiss plane was lowered, the displacement for each gneiss plane at most would amount to 1,000 meters. As it is known for a fact that gneiss planes may, under pressure of ice for instance, subside and again rise more

than 200 meters without being broken, it is not inconceivable that the displacement may have taken place along a single fissure or a very narrow fracture zone without the gneiss planes being broken up into smaller areas.

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THE LAVA FIELD OF THE PARANÁ BASIN, SOUTH AMERICA

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This paper is a summary of the most important results of the writer's recent journeys of 8,500 miles, during seven months, in the eastern River Plate region of South America. The late Dr. J. C. Branner, in May, 1921, expressed the opinion that the "trap" field of southern Brazil and adjacent regions was possibly greater in extent than any other. The writer's subsequent field studies have demonstrated that the area covered by basaltic lavas is at least nearly as great as the combined areas of the Deccan and Columbia River basalt fields, heretofore supposed to be the two largest in the world.

Either basalt or diabase ("dolerite") is found almost everywhere in the hydrographic basin of the Paraná River, and extends beyond into the southern part of the Amazons hydrographic basin (Amazonia) and the eastern part of the Rio Paraguay drainage basin. The drainage basin of the Uruguay River, with extensive areas of basalt, probably was, up to very recent times, directly tributary to the Paraná. Structurally all this region is a single vast downfold (geosyncline), bounded on all sides by outcrops of a pre-Cambrian or early Paleozoic basement complex of plutonic and metamorphic rocks. In this complex the major structural trends, so far as known, are northeast-southwest, parallel to the southern Brazil and Uruguay coast line, and to the major axis of the Paraná downfold. Apparently this eastern region of present hill ranges was one of lofty mountains in late pre-Cambrian or early Paleozoic times. Today the highest mountains and ridges are composed either of folded and faulted metamorphic quartzites or of great bosslike masses of syenitic intrusives.

PREVOLCANIC SEDIMENTARY HISTORY

The sedimentary history is relatively simple, exhibiting a rather surprising uniformity of depositional conditions. Non-fossiliferous basal conglomerates, shore-line sandstones, and alluvial deposits are followed in the same depositional cycle by marine Lower Devonian shales and sandstones, deposits of a sea which covered a vast area in the interior of South America.[1] There followed an epoch of erosion which removed much of the Lower Devonian and possibly older sediments. Then, if not, indeed, earlier (pre-Devonian) it would appear that the approximate eastern and northern limits of the Paraná depositional basin were formed. As yet, no great angular unconformity between Lower Devonian and superjacent beds has been determined.

Nearly all later sedimentation in this basin, so far as yet indicated by outcropping rocks, was of the continental type, although some diminutive brachiopods, presumably marine, have been found in the lower coal measures in southern Paraná, and mollusks, more probably brackish-water or fresh-water forms, in the Estrada Nova beds of both São Paulo and Paraná. It is possible that some contemporaneous marine deposits were laid down in the now covered central or western part of the geosyncline.[2] I. C. White's stratigraphic classification[3] applies to all the sedimentary region east of the basalt. The first deposits of the continental sequence were of alluvial, fluvio-glacial, glacial-morainic, floating ice, and palustrine origin, and are found in the Brazilian states of São Paulo, Paraná, and

[1] Fossiliferous Lower Devonian has been found in the Falkland Islands, the province of Buenos Aires, the eastern Andes of Bolivia, on both sides the lower Amazon geosyncline, in Paraguay, and in the Brazilian states of Paraná, Matto Grosso, and Goyaz. In southern Goyaz, twelve miles north of the town of Rio Bonito, the writer found shales lithologically similar to those of Ponta Grossa in Paraná and carrying Dalmanites.

[2] Siemiradski's (*Geologische Reisebeobachtungen in Sudbrasilien*, Sitz. Ber. Akad. Wiss., Mat.—nat. Cl., Bd. 107, Abt. 1, pp. 23–39, figure and plate, Vienna, 1898) locality and age determinations of some supposed Permian marine fossils from the mountains of the Matto Grosso–Paraguay frontier are doubtful. These fossils were worn as charms by Indians and may have come far distant from where Siemiradski supposed. Also, they are not age-diagnostic; it is possible they are as old as Devonian.

[3] *Report on the Coal Measures and Associated Rocks of South Brazil.* In English and Portuguese. Report to the Ministry of Industry, etc. Rio de Janeiro, 1908.

northern Santa Catharina.[1] Alluvial sandstones and shales, coal beds and palustrine carbonaceous and bituminous shales, laid down on low flattish surfaces, perhaps slowly sinking, followed. These are the Rio Bonito beds of Uruguay,[2] Rio Grande do Sul, Santa Catharina, Paraná, and southern São Paulo. The Rio Bonito in Rio Grande do Sul, Uruguay, and southern Santa Catharina rests, so far as known, directly on the basement complex, often with relatively little basal conglomerate. Following the Rio Bonito is the Palermo, a relatively thin formation of shales. Next is the Iraty, also relatively thin, dark bituminous (sapropelitic) shales with some interbedded limestones and cherts, carrying the fresh-water reptiles, Stereosternum and Mesosaurus (also found in Cape Colony) and numerous ostracods. The Iraty appears to have been a fresh-water lake deposit. It outcrops in a northeast-southwest direction for about 800 miles, extending from northern São Paulo to central Uruguay. The cycle was ended by the deposition of clays with a few thin concretionary limestones, some of which have fish and molluskan fossils—the Estrada Nova beds. All the deposits of this first depositional cycle have been referred to the early Permian or "Permo-Carboniferous," but at least the glacial and coal formations may prove to be late Pennsylvanian. The total thickness averages about 1,650 feet (500 meters).

An erosional unconformity intervenes between the sequence just described and the overlying red beds. This unconformity, first noted by I. C. White, was found by the writer in São Paulo, Paraná, and northern Santa Catharina; hence it probably denotes a time break of considerable importance. The lower of the two red bed formations, the Rio de Rastro—only 300 feet thick at the north but apparently thicker in Rio Grande do Sul—has yielded in Rio Grande do Sul a few reptilian remains[3] which appear to indicate its approximate contemporaneity with the whole of the Triassic part of

[1] Glacial beds may some time be found in Rio Grande do Sul. A likely area is in the country between Suspiro and Bagé, particularly near Ibaré in the southern part of that state. The best section of glacial beds now known in Brazil is along the São Francisco Railway on the northern Santa Catharina border.

[2] The writer is indebted to Karl Walther's publications for numerous data on the geology of Uruguay.

[3] The best-known collecting grounds are just south of Santa Maria and on the Rio Grande–Santa Catharina border northeast of the seaport of Torres.

the Karroo of South Africa. Shales and sandstones, inclined, lenticular, and cross-bedded, and a few conglomerates make up the formation. Overlying is the São Bento heavy and cross-bedded sandstones with a few conglomerate beds. Volcanism began after the deposition of an average of 650 feet of the São Bento sandstone.

We have so far outlined conditions in the eastern part of the Paraná Basin. On the north and west in eastern Paraguay, central and southern Matto Grosso, southern Goyaz, and the western triangle of Minas Geraes the deposits of the first cycle are not yet known with certainty, but the red beds there lithologically resemble the Rio do Rastro and São Bento of the eastern part of the basin.

THE PARANÁ BASALTS AND DIABASES

Extent of basalt area.—The sketch map (Fig. 1) which accompanies this paper represents an attempt to outline the present minimum extent of the basalt flows in the Paraná Basin as determined by former geologic explorers in Brazil, by Karl Walther in Uruguay, and the writer in the western triangle of Minas Geraes, southern Goyaz, central and southwesternmost Matto Grosso, western Paraná, eastern Paraguay, northern Argentina, and northwesternmost Uruguay. The boundaries are fairly well determined by prominent erosional escarpments on all sides except in eastern Paraguay and northern Argentine, where the mesopotamian alluvial deposits of the River Plate lowlands, and the Pampean loess, obscure or entirely conceal the bed rock. There is quite possibly a larger area of basalt in Paraguay and Argentina than is represented on the map. Any other possibly important errors, more particularly on the north and northwest boundaries, can safely be attributed to the imperfections in all existing maps. There is at least one considerable outlying area of basalt in southern Rio Grande do Sul not included in the forthcoming figures and not represented on the map. A considerable dome-shaped area around Lages in southeastern Santa Catharina, now stripped of lava cover, is included in the computations.

The basalt flows, as tentatively mapped, now cover an area of over 300,000 square miles (800,000 square kilometers). Assuming the average thickness of the basalt flows as 1,000 feet, their total

FIG. 1.—Sketch map of Paraná Basin, South America, showing distribution of basalt flows. By Charles Laurence Baker.

Scale 1:10,000. 1" = 160 mi.

volume is about 50,000 cubic miles. This is of the order of volume of a great mountain range. It is certain that the basalt once covered a much greater area, from which it has been removed by erosion during all the latter Mesozoic and Cenozoic. The entire region of sedimentary rocks in southern Brazil, east of the present limits of the flows, is cut by extraordinary numbers of sills and dikes of diabase. They are less numerous in Rio Grande do Sul, but in the other southern states of Brazil one would scarcely ever be out of sight of one or more intrusives if the country was not densely forested. The sedimentary rocks cut by diabases cover an area of about 75,000 square miles (nearly 200,000 square kilometers). Combining the area of present flows with the area along its eastern margin which probably was once covered, we arrive at the total of more than 375,000 square miles (or about 1,000,000 square kilometers).

Even this may be far short of the total original area. At no place did the writer succeed in reaching the limit of the diabasic intrusives. He found them in the basement complex of southeastern Brazil, also cutting sedimentary rocks as far west as the Gran Chaco in the vicinity of Asuncion, Paraguay, and Walther found them as far south as Montevideo. The writer found them in the southern part of Amazonia. A still greater extension is problematical. Nevertheless, in Piauhy and Maranhão, states of northern Brazil, sediments referred to the Permian and Triassic are cut by diabases, and amygdaloidal sheets are intercalated with the youngest sandstones of the "Permo-Trias" series. Great intrusives of diabase which cut sediments as late as the marine Upper Pennsylvanian and the overlying Red Beds, and antedating sediments referred doubtfully to the mid-Tertiary on both sides of the lower Amazon geosyncline, likewise the great masses of trappean rocks forming a part of the extensive mountainous area on the frontiers of Brazil, Guiana, and Venezuela, may be of the same age as the flows and intrusives of the Paraná Basin. There are heavy flows of basalt interbedded with the red continental sandstones of northwestern Argentina, but these the Argentine geologists, somewhat doubtfully perhaps, consider Cretaceous. There are also diabase dikes in the Falkland Islands.

The minimum thickness of the basalt flows, not including what has been removed at the top by erosion, is more than 2,000 feet (White) in the Serra Geral between Lages and the Tuberão Basin in Santa Catharina, 1,550 feet in northeastern Santa Catharina (according to Woodworth),[1] 1,300 feet at Porto União on the Paraná–Santa Catharina border, 800 feet in the Serra do Esperança between Imbituva and Guarapuava in south-central Paraná, at least 1,150 feet not including the basal portion at Porto Santa Helena on the Rio Paraná on the west boundary of the state of Paraná, 1,150 feet without the basal portion at Marcellino Ramos on the Rio Uruguay on the Santa Catharina–Rio Grande do Sul border, probably 1,000 feet or more north of Santa Maria, Rio Grande do Sul, at least 750 feet without the basal portion at Santa Rita on the Paranahyba River on the Goyaz–Minas Geraes border, at least 600 feet without the basal portion at Jatahy, southern Goyaz, and 400 feet in the Serra do Itaquery in central São Paulo. These figures may indicate that the thickest flows are in Santa Catharina, Paraná, and Rio Grande do Sul, but such a generalization is untrustworthy because of the erosion varying in amount from place to place.

Lithology.—The lower sheets intercalated with relatively thick beds of São Bento sandstone are for the most part not included in the thickness given above. These are either flows interbedded with the sandstones, or are intruded as sills. It is often difficult or impossible to choose between these two alternatives since some of the rocks known to be flows have as dense a texture as those known to be intrusives, and the silicified sandstones of the São Bento, intercalated between these lower sheets, may have been hardened by flows or cemented and partially "metamorphosed" after the volcanism, for instance by the mingling of underground waters. There is usually some intercalated sandstone, in relatively minor proportions, in the upper main mass of the lava, but in Santa Catharina and western Paraná no intercalated sandstone was detected in more than 600 miles of traverse. There is accordingly some likelihood that these upper sandstones are more abundant near the periphery of the original lava field.

[1] *Geologic Exploration in Brazil and Chile*, Bull. Comp. Zoöl., Harvard College.

Many of the flows are vesicular, and some even cavernous. Others are very dense, in which case there is some columnar structure. The amygdaloidal fillings are quartz (both common and amethystine), agate, chalcedony, calcite, zeolites, native copper, copper minerals, and green iron silicate. There has nowhere been found any pyroclastic material, or any indication of true volcanoes, although some of the rocks are so greatly decomposed that the original nature is not known. The great number of dikes in the sedimentary area east of the basalt escarpment shows how widespread were the fissures by which the lavas reached the surface, and since the general thickness is maintained far beyond regions where these fissures are visible, we may assume that fissure eruptions were prevalent throughout the entire Paraná Basin. The fissuring, so far as known, was not accompanied by great faulting.

In composition the basalts and diabases ("dolerites") range from andesite and olivine-free augite-porphyrites to typical limburgites with abundant olivine.

Later sedimentation.—Eruptions began during the time of deposition of the upper part of the São Bento sandstone. At first there appears to have been alternation of lava flows and beds of sandstone; later on came the epoch of greatly predominant volcanism. The lava flows were later deformed into the Paraná geosyncline as we find that structure today. The deformation renewed erosive activity on the bounding crystalline areas to the north, northeast, and east, and a supra-basalt formation of sands and conglomerates, called in São Paulo the Bauru formation, was deposited on the rather slightly eroded lava surfaces. Today a vast surface of the supra-basalt formation constituting a depositional plain is found in western São Paulo, southern Goyaz, and the western triangle of Minas Geraes; remnants of smaller extent exist in southeastern Matto Grosso, and on the great divide between the Jacuhy and Ibicuhy rivers in north-central Rio Grande do Sul. The Bauru formation of western São Paulo contains large dinosaurs of supposed Wealden (late Jurassic or early Cretaceous) age. The surface of the supra-basalt formation slopes very gently toward the Alto (upper) Paraná and Paranahyba rivers in the northeastern part of the

Paraná Basin, but the slope may be entirely or in large part depositional. The supra-basalt formation much resembles in character and mode of origin the later Cenozoic deposits of the Llano Estacado of Texas and New Mexico, and like the latter may be of widely different ages at different localities. The only other supra-basalt deposits, besides stream alluvium, yet known, are sediments, probably eolian, of the Pampean loess in northeastern Argentina, western Uruguay, and southwestern Rio Grande do Sul.

Age of the basalt flows.—Assuming that the age of the upper part of the Rio do Rastro red beds is that of the Beaufort beds of the upper Karroo of South Africa, with which they are correlated by Smith-Woodward, and that the Bauru dinosaurs belong to the Wealden, we have an interval between some stage of the Triassic—presumably later Trias—and the beginning of the Cretaceous, during which there were (1) deposition of the São Bento sandstone, (2) the outflow of the basalt, (3) the deformation of the lavas, and (4) a subsequent period of erosion. This would indicate most probably that the basalt eruptions fell within the Jurassic, possibly in the upper Triassic. There is, perhaps, some reason for uncertainty concerning the exact stage of the Trias occupied by the upper Karroo of South Africa and the upper Rio do Rastro of the Paraná Basin. At a time more or less the same as the deformation of the lavas and formation of the Paraná geosyncline, there were formed basins in the crystalline area of easternmost Brazil which became sites of deposition of Cretaceous and early Tertiary marine sediments.

Perhaps contemporaneous was the formation of the long trough within the basement complex which parallels the Atlantic coast line from Campos in easternmost Rio de Janeiro state, to Curityba in Paraná, followed by the valleys of the Parahyba, the upper Tieté, the Iguapé, and Ribeira and covered by Tertiary lake deposits along the upper courses of the Tieté and Parahyba.

Near the time or contemporaneous with the basalt eruptions there was formed the eastern pre-Andine and eastern Andine depositional basin, in which marine sediments were deposited throughout the Jura and part of the early Cretaceous, and continental sediments during the later Cretaceous and Cenozoic. The epoch of outflow of basalt occurred at or near the time of breaking-up

of the supposed Gondwana land and the formation of the South Atlantic Basin.

Physiography.—Upon the deformation of the lava into the Paraná geosyncline the drainage became consequent to the structure. The geosyncline plunged to the southwest, and the master stream, the Paraná and its headwaters tributary, the Paranahyba, occupied the trough of the geosyncline. These two streams follow the structural trough in the lava for more than 1,000 miles; they appear to have come into existence near the beginning of the Cretaceous period, and to have persisted in their courses. The tributaries either took the shortest distance and line of maximum gradient down the flanks of the geosyncline, or assumed courses in the troughs of cross- or subsidiary synclines. A number of the greatest tributaries of the Paraná River still flow in the troughs of the cross-synclines. The basalt is both so thick and so resistant to erosion that there appears to have been little important subsequent drainage adjustment within the area still covered by lava.

The intercalation of quartzose sandstones with the lava flows and the great preponderance of quartzose and other detritus derived from the basement complex in the supra-basalt formation indicate that the surfaces of the basement complex stood higher than that of the lavas on the north, northeast, and east, in which directions the detritus becomes increasingly coarser. This is in contrast to present topographic conditions in which erosion escarpments of the lava stand at higher altitudes than the less resistant sedimentaries, and a part of the basement complex crystallines.

At the point where the Paraná River crossed the southwestern margin of the lava, falls or rapids were originally formed. The lava surface there constituted a base level for all the drainage of the Paraná Basin above that point. On this local base level of the then slightly denuded lava surface were deposited the supra-basalt sands and gravels. Their original surfaces, still in large part intact, sloped very gently southward in southern Goyez and central-eastern Matto Grosso, southwestward along the Paranahyba drainage basin in southeastern Goyaz and the northern part of the western triangle of Minas Geraes, and west-northwestward in western São Paulo. Along the valley of the Alto (upper) Paraná

from north of Porto Tibiriça to the falls of La Guayra or Sete Quedas, for a distance of 250 miles or more, these sandstones have strongly inclined bedding, very delta-like in nature, dipping in the direction of the flow of the river. Should one make the error of considering these sandstones originally deposited horizontally and later tilted, he would compute their thickness in many thousands of feet.

The Paraná River flows in a canyon with walls of solid basalt all the way from the falls of La Guayra or Sete Quedas, to a point 12 miles below the city of Posadas, territory of Missiones, Argentina, a straight line distance of nearly 250 miles. The breadth of the river just above La Guayra Falls is 12,600 feet and its mean depth at low water is perhaps 3 feet. The breadth of the river at the foot of the falls is 262 feet. The height of the uppermost (lowest) fall is 50 feet, but there are eighteen different groups of falls around both sides and at the head of a narrow trench inclined downstream, and 10,750 feet in length. For 100 miles below the present falls there is a difference of 100 feet below high- and low-water levels in the river. The river falls 373 feet in the distance of 40 to 45 miles between the head of the falls and Porto Mendez.[1] There is a strong gradient in the river all the way from the latter place to within 25 miles of Posadas, at which place a cross-syncline in the basalt brings the supra-basalt formation down to the low-water level. With this exception the entire gorge of the river between La Guayra Falls and a point 12 miles below Posadas is cut through very resistant solid basalt, and at no place is the base of the basalt exposed, although possibly some important undermining action has taken place under the low-water surface. Not only are the falls of La Guayra the mightiest in volume in the world, but they are one of the oldest, if not the very oldest, known.

The lowest or great falls of the Iguassú River, now situated 12 miles above the confluence of that river with the Paraná, have a mean fall of about 230 feet, all through solid basalt. The great Iguassú Falls are said to have a volume greater[2] than those of

[1] The writer is indebted for these data to Mr. Wilson Sidwell, C.E., who has made the only accurate survey of the falls.

[2] Probably overestimated, at least as respects mean flow.

Niagara, but they have receded only about one-seventh as fast as those of La Guayra.

Sandstones intercalated in the basalt are less resistant, the vesicular flows decompose and erode more readily than the denser lavas, and local columnar structure aids erosion. The result has been the formation of step and terrace profiles along the valleys both longitudinally and transversely, and of rapids and waterfalls numbered by the thousands, with intermediate stretches of sluggish and ponded waters throughout the entire drainage area of the Paraná Basin. Rapids, waterfalls, and local base levels are also abundant where dikes and sills are found in the sedimentary rocks.

The present topography within the lava area has, in the principal interstream divides, flat meseti-form plateaus capped by lava or by the supra-basalt formation. These plateaus have great extension in all the Brazilian portion of the Paraná Basin, except in Rio Grande do Sul, where erosion has reached for the most part the stage of maturity. The streams have dissected deep canyons and gorges and have falls and rapids. The topography is, therefore, still in the youthful stage of development but one can venture to assert that it is one of the *oldest* known youthful topographies, considering the absolute length of time it has persisted. On the whole the lava field is a plateau with surfaces gently sloping toward the trough of the geosyncline, partially dissected by youthful canyons and gorges, and bounded for the most part by high recessional erosion escarpments. Those portions of the Paraná Basin lying without the lava area have mature topography, very rugged aside from some local base-leveled areas.

The residual soils—products of decomposition of the basalt—are confined in large part to the flat upland interstream surfaces, except in Rio Grande do Sul. The sides and bottoms of the canyons and gorges are largely bare rock surfaces. The rain may pour down for a week, yet the swollen streams with their average high gradients run fairly clear at the end of the deluge. The main reasons for this appears to be the dense cover of arboreal and smaller vegetation which inhibits to a very great extent sheet wash, and the

low gradients of the instream flats. Between the falls and rapids there are long stretches of slack water where there is deposition of detritus.

The rolling uplands of Rio Grande do Sul are grass-covered. The Rio Jacuhy which drains the southeastern part of the basalt area of that state has the advantages of relatively short course and steep gradients to the Atlantic. The local base level of the middle Uruguay, formed by the basalt falls near Salto, Uruguay, and Concordia, Argentina, lies at a relatively low level. These factors, combined possibly with others, have operated to bring about a more advanced stage of erosion over a large portion of the lava region of Rio Grande do Sul.

The five major tributaries of the Paraná in the states of São Paulo and Paraná—namely, the Rio Grande, the Tieté, the Paranapanema and its largest tributary, the Tibagy, the Ivahy, and the Iguassú—have their sources east of the present lava area (all of them except the Ivahy in the crystalline area of the Serra do Mar, very close to the Atlantic Coast)—flow downstream across the sedimentary area, and cut through the eastern scarp of the basalt. It is probable that these rivers have largely persisted in initial courses determined by the westerly slope of the deformed land surface. The only one of the five which shows marked subsequent adjustment is the Ivahy which for a portion of its course flows at the eastern foot of the lava escarpment, shifting its channel down dip in accordance with Gilbert's Law. It is probable that the original surface had greater gradient near its eastern margin than in the vicinity of the geosynclinal axis. This made possible more rapid erosion in the headwater courses of these streams, and perhaps the lava cap was thinner there than farther west. These streams, as well as some original tributaries of the Paraná in Goyaz, Matto Grosso, and Minas Geraes later beheaded by tributaries of the Amazons and São Francisco, originally drained areas of the basement complex which were the sources of the supra-basalt formation. The basalt lies directly upon the basement complex in the headwaters regions of the Rio Grande and Paranahyba.

The Paraná Basin has been land since the Trias and with the possible exception of the Guianan Highlands and the eastern Brazil

crystalline highlands, is perhaps the oldest land in South America. The vegetation of the Paraná Basin has an archaic cast. Araucarians, tree ferns, and primitive angiosperms are characteristic. Among old types of animals, we find lung fishes and primitive birds. The Paraná Basin may have been one of the centers of development and distribution of the present fauna and flora of South America.

Latest movements.—Any diastrophic events of possibly later date than pre-Cretaceous will be difficult to detect in the Paraná Basin. The Atlantic Coast and the alluvial basin of the River Plate, are more favorable regions for their detection.

There is great general similarity in stratigraphic, volcanic, and structural features between the Karroo Basin of South Africa and the Paraná Basin of South America. The land-laid deposits of the Karroo System of South Africa are very similar in mode of origin and fossil content to those of the Paraná Basin. There is a great geosyncline in South Africa also. Du Toit[1] has recently summarized the data on the Stromberg volcanic series and complementary doleritic intrusives of South Africa. He says the intrusives cover an area of fully 220,000 square miles between the twenty-eighth and thirty-third parallels, and originally extended eastward into the Indian Ocean and probably westward into the Atlantic. If outlying tracts are connected, the area of intrusions aggregate more than 325,000 square miles. The dolerites probably date from Rhaetic or Lias, at latest from Middle Jura. The effusive outflows of the Stromberg volcanics occupy the central part of the Karroo Basin and are confined to an area 350 miles long and 150 miles broad with Basutoland as the center. As du Toit points out, the mid-Mesozoic shows in South America, South Africa, Tasmania, Antarctica, peninsular India and in the eastern United States (Newark series) the greatest known eruptions of trappean rocks.

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[1] "Karroo Dolerites of South Africa," etc., *Trans Geol. Soc. South Africa*, Vol. XXIII, pp. 1–42.

Petrological Abstracts and Reviews

ALBERT JOHANNSEN

WASHINGTON, HENRY S. "The Charnockite Series of Igneous Rocks," *Amer. Jour. Sci.*, XLI (1916), 323–38.

Five specimens of typical representatives of the charnockite series of India from the original localities are here re-examined by Doctor Washington, and five new analyses are given. A comparison with the older analyses shows considerable variation. The rocks were also determined by the Rosiwal method. The percentage of minerals given for the hypersthene-granite (charnockite) places the rock in 226′ of the reviewer's system, a normal hypersthene-granite. The feldspar of the intermediate charnockite or hypersthene-quartz-diorite is not determined separately in percentages. The total feldspar is given as 55.5 per cent, but from the description it is impossible to determine the proportions. From the name given to the rock and from the statement, "a great majority of the feldspar grains had a refractive index of about that of Ab_3An_1," the proportion of alkali feldspar must be small, although the statement is made that "the feldspar is, apparently, largely alkalic, some of it showing the microcline grating, while the greater part shows no twinning lamellae." Further in the summary, the range of the rocks is said to be "through hypersthene-quartz-diorites (and possibly monzonites), etc.," indicating the possibility that the position of the rock is farther toward the orthoclase side than the name quartz-diorite would indicate. Basic charnockite gives a mode corresponding to 3312, or normal norite, assuming the feldspar is 95 per cent or more labradorite. The hornblende-hypersthenite or bahiaite is 426.

WASHINGTON, HENRY S. "Persistence of Vents at Stromboli and Its Bearing on Volcanic Mechanism," *Bull. Geol. Soc. Amer.*, XXVIII (1917), 249–78, pls. 4, figs. 15.

It is pointed out that the vents of Stromboli have been persistent in location for a very considerable time. They cannot, therefore, have originated by explosive agencies, but can best be explained on the basis of the "gas-fluxing" hypothesis of Daly.

WASHINGTON, HENRY S. "Italian Leucitic Lavas as a Source of Potash," *Metallurgical and Chem. Engineering*, XVIII (1918), No. 2. Pp. 21.

The Italian volcanoes contain at least 10,000,000,000 tons of K_2O, which at the present rate of consumption could "on paper" supply the United States for 50,000 years *if* a profitable method of extraction could be found.

WASHINGTON, H. S., and KOZU, S. "Augite from Stromboli," *Amer. Jour. Sci.*, XLV (1918), 463–69.

It is not the intention to give mineralogical reviews in this column. This paper is simply listed to point out the desirability of having at least three things determined in a rock: (1) a chemical analysis of the rock itself; (2) chemical analyses of the component minerals; (3) percentages of the actual minerals present in the rock. It is known that such minerals as the pyriboles and biotite vary in composition in different rocks, consequently to determine whether there is any relationship between the kind of rock and the composition of the component minerals, all of the factors mentioned should be determined.

WASHINGTON, HENRY S. "Italite, a New Leucite Rock," *Amer. Jour. Sci.*, L (1920), 33–47. Also a preliminary paper in *Jour. Wash. Acad. Sci.*, X (1920), 270–72.

Normal leucitites contain nearly as much pyroxene as leucite. Here is described a leucocratic leucitite, containing about 90 per cent leucite, and to it is given the name *italite*. According to the reviewer's system it is not quite a true leuco-leucitite (1120) for it falls just over the line in the second class. The leucocratic minerals amount to 94.01 per cent while in the leucocratic class the line is drawn at 95 per cent. The rock is, however, the one nearest this position that has been found. A striking characteristic is the high percentage of potash in the analysis, 17.94, or greater by 50 per cent than any previously recorded.

An ejected block from Monte Somma is also described. This resembles the italite but contains melilite as the last mineral to crystallize. The mode given is leucite 60 per cent, melilite 18 per cent, pyroxene 20 per cent, and magnetite 2 per cent. To this melilite leucitite is given the name *vesbite*. In the reviewer's system it is 2120.

Washington proposes *albanite* to replace leucitite for mesocratic types.

WASHINGTON, HENRY S. "The Rhyolites of Lipari," *Amer. Jour. Sci.*, L (1920), 446–62.

Publishes five new analyses of the Lipari rhyolites, a hyalodacite from Monte Sant' Angelo, Lipari, and an obsidian from the Island of Milos. The following refractive indices, determined by Doctor Merwin, are given: Obsidian, Rocche Rosse 1.488–89, from Forgia Vecchia 1.490, from Monte Arci 1.487–89, from Milos 1.490, pumice from Monte Pelato 1.499.

WASHINGTON, HENRY S. "The Chemistry of the Earth's Crust," *Jour. Franklin Inst.*, CXC (1920), 757–815, figs. 6.

Briefly discusses the interior of the earth, mineral and chemical characters of igneous rocks, the average igneous rock, average composition of the earth's

crust, petrogenic and metallogenic elements, comagmatic regions, chemical composition and rock densities, and the relations between rock densities and elevations of continents.

WASHINGTON, HENRY S. "The Granites of Washington, D.C.," *Jour. Washington Acad. Sci.*, XI (1921), 459–70, fig. 1.

Two types of granite occur as intrusives in the granite-gneiss of the District of Columbia, biotite-granite and muscovite-biotite-granite. Two new analyses of the mode of the former are given. The mineral composition places it in 226, very near 225, orthogranite, of the reviewer's system. It contains 6 per cent epidote besides the essential constituents indicated in the name. Two new analyses are given of the two-mica-granite, but no modal percentages. Both types show cataclastic texture. Epidote is developed in the portions of the biotite-granite most metamorphosed, but is absent in the two-mica-granite. It is said to be apparently wholly secondary.

WASHINGTON, HENRY S. "Obsidian from Copan and Chichen Itza," *Jour. Washington Acad. Sci.*, XI (1921), 481–86, fig. 1.

Describes two Yucatan obsidians, one black, the other brown, from implement cores and beads. Washington thinks both types of obsidian came from the vicinity where found. The black obsidian is of the usual type, the brown one, however, belongs to the alcalic series.

WASHINGTON, HENRY S. "The Lavas of the Hawaiian Volcanoes," *Hawaiian Annual for 1922*. N.p. 1921.

A popular article on the various Hawaiian lavas.

WATANABE, MANJIRŌ. "Cortlandtite and Its Associated Rocks from Nishi-Dōhira, Prov. Hitachi," *Science Reports* (Tōhoku Imperial University), Ser. III, Vol. I (1921), pp. 33–50, figs. 4, photogravure pl. 1.

Intruded in a region of biotite-schist and biotite-gneiss is a small body, possibly a laccolith. The mass is made up of various types of rocks, all parts of the same intrusion. The inner core is cortlandtite. Above this is hornblendite, which is succeeded successively by thin layers of quartz-bearing-gabbro and quartz-diorite. The cortlandtite consists of greenish hornblende poikilitic with pyroxene (hypersthene and augite) and olivine in less amount, and accessory biotite, apitite, ilmenite, zircon(?), and magnetite. The hornblendite (so called) is a coarse granitoid rock, chiefly of dark minerals, hornblende, less augite than the cortlandtite but more biotite, and finally an unnamed plagio-

clase filling the interstices between the dark minerals. The quartz-bearing-hornblende-gabbro consists of green hornblende, dark-brown biotite, and white plagioclase. No percentages are given but the statement is made that "the first one still predominates to a greater amount than the other (sic)," probably meaning the dark exceeds the light. The plagioclase is said to have refractive indices of 1.550 to 1.573 in different crystals, indicating andesine to labradorite. Quartz is accessory, as is also apatite, pyrite, and magnetite. The quartz-diorite has a thickness of not more than one meter and grades into the underlying gabbro. It consists of quartz, andesine, hornblende, and biotite, with accessory apatite, titanite, zircon, magnetite, and pyrite. If, then, this mass represents a single body, which has been differentiated, it indicates the manner of the separation of the various minerals. "In the dentral and lower part olivine and hypersthene are present, and large crystals of hornblende enclose all other constitutents, indicating . . . . that it was the last phase in the course of consolidation of the magma at this part. Towards the upper layers, olivine and hypersthene decrease in amount and finally disappear in the hornblendite. Here augite decreases in quantity and ceases to show the poikilitic relation to hornblende, while plagioclase appears filling up the interstices of the femic (sic) minerals. In a still upper part formed of gabbro, plagioclase becomes a member of the essential ingredients. A prominent feature of this part is, however, the appearance of quartz, though it is small in quantity. Here this mineral is the phase which was last to crystallize out. Further, approaching the upper marginal part, plagioclase and quartz increase in quantity and form the essential components."

No modal percentages are given but there are chemical analyses of the first three rocks.

WEISE, E., and UHLEMANN, A. "Sektion Auerbach-Lengenfeld," *Erläut. geol. Spezialk. Königr. Sachsen.* Leipzig, 1915, 2d ed. Pp. 57, figs. 3.

This quadrangle contains the three large granite masses of Bergen-Lauterbach, Eibenstock, and Kirchberg, between which are slates, phyllites, and quartzites, metamorphosed by the granite. Various analyses are given, the contact action is described, and the associated dikes of aplite, kersantite, and mica-porphyrite are discussed. Two bowlders of melilite-nepheline-basalt were found at the eastern border of the quadrangle, but the source could not be discovered.

WEISS, GUSTAV. "Beiträge zur petrographischen Erforschung des Unteren Buntsandsteins," *Ber. d. Oberh. Ges. f. Natur.—u. Heilkunde. N. F. Naturw. Abtlg.*, VI (1914). Pp. 14, pl. 1, figs. 2.

The quartz-feldspar-sandstone at Gisselberg, near Marburg, consists of 20 to 30 per cent feldspar and 70 per cent quartz. The feldspar is about half

and half orthoclase and plagioclase. The components are held together by their fine grain, by quartz, and by small amounts of ferritic and claylike substances which originated from alteration of the constituents. An important part of this study is the use made of pairs of alternating coarse and fine layers for the determination of the conditions of sedimentation.

WRIGHT, FRED E. "The Petrographic Microscope," *Jour. Optical Soc. Amer.*, I (1917), 15–21, fig. 1.

Gives a brief description of the petrographic microscope and describes its use in the determination of various optical properties.

WRIGHT, FRED E. "The Petrographic Microscope in Analysis," *Jour. Amer. Chem. Soc.*, XXXVIII (1916), 1647–58.

Discusses the applicability of the petrographic microscope to certain classes of problems of a chemical nature. The differences between an ordinary and a petrographic microscope are described, and the various optical properties used for diagnosis are briefly stated.

WRIGHT, FRED E. "Recent Improvements in the Petrographic Microscope," *Jour. Washington Acad. Sci.*, VI (1916), 465–71, fig. 1.

Describes a sliding objective changer, the removal of astigmatism in the analyzer, the prism method for observing interference figures, and a device for use in the accurate measurement of extinction angles.

WRIGHT, FRED E. "Note on the Lithophysae in a Specimen of Obsidian from California," *Jour. Washington Acad. Sci.*, VI (1916), 367–69.

The lithophysae in a specimen of obsidian from Little Lake, about 40 miles south of Owen's Lake, Inyo County, California, are thought to be due to hydrostatic tension resulting from the contraction of the magma during cooling and outward pressure of the gases set free during the crystallization of the spherulites. The minerals of the spherulites are potash-soda feldspar, tridymite, and magnetite, with some fayalite, and occasional jet black mica.

WRIGHT, FRED E. "A Precision Projection Plot," *Jour. Washington Acad. Sci.*, VI (1916), 521–24, fig. 1.

Describes a stand with a frosted glass top, illuminated beneath by an electric lamp, upon which is placed a stereographic projection net 40 cm. in

diameter, printed on thick, transparent celluloid, and with curves at 1° intervals. The celluloid disk rests on the glass disk and by means of centering screws can be centered to the axis of rotation of an outer steel ring which carries the tracing paper on which measurements are plotted. An accuracy of 0.1° is attainable.

WURM, CLEMENTINE. "Die Mineralien in den Einschlüssen des Basaltes vom Finkenberg bei Beuel," *Centralbl. f. Min. etc.*, 1921, 581–90.

Describes all the minerals found in inclusions of basalt from the Finkenberg region, and discusses their origin and genetic relationships.

ZANTINI, WILLY. "Der Noseanphonolith des Schnellkopfs bei Brenk und die anstehenden Noseanphonolithe überhaupt mit besonderer Berücksichtigung ihres geologischen Auftretens und ihrer Einschlüsse," *Neues Jahrb.*, B. B. XXXVIII (1914), 587–642, pls. 2.

Underlying the Laacher Sea there was evidently a foyaitic magma which solidified at depth as a plutonic rock and its accompanying dikes, and now expressed by numerous inclusions in the extrusives, and in an extrusive noseanite phonolite and its tuff. This extrusive is here described in considerable detail, with analyses and descriptions of the component minerals.

REVIEWS

The Tin Resources of the British Empire. By N. M. PENZER. London: William Rider & Son, Limited, 1921.

This book constitutes a useful reference work for geologists, mining engineers, and others who are in search of information on specific tin-producing districts in the British Empire. The book contains voluminous statistical tables recording the trade in tin within the British Empire and production statistics where such are available. For the Cornwall district production tables for individual mines are given.

As the book does not profess to be primarily geologic there are no geologic maps and the geologic descriptions are commonly short; two geologic sections across the Malay Peninsula prepared by J. B. Scrivenor, Government Geologist of Malaya, are, however, included.

Methods of prospecting, mining, and ore treatment are discussed for certain regions, notably Malaya. The book closes with brief chapters on the "Industrial Applications of Tin," "Prices, Sale of Tin," and "World's Output," and with a Bibliography of forty pages in which the titles are listed geographically with the exception of those which are general in their scope. To the geologist this Bibliography will be found to be less exhaustive and less useful than that compiled by F. A. and Eva Hess, published as Vol. LVIII, No. 2, of the Smithsonian Miscellaneous Collections.

E. S. B.

Determinative Mineralogy. By J. VOLNEY LEWIS. Third edition. New York: John Wiley & Sons, 1921. $3.00.

In this new edition Professor Lewis has followed the general plan of the second edition, so far as the blowpipe work and the chemical properties of minerals are concerned. On these points, therefore, the new edition needs no comment, although minor changes, such as the omission of some twenty-five of the rarer minerals and the use of a larger-size page, may be mentioned. The addition of determinative tables for some 290 minerals, covering 138 pages, based purely on physical characteristics, is an innovation of great value which will commend itself both to those who use the book in the field, and those who use it in the classroom.

The physical classification of the minerals is based on streak, color, cleavage, and hardness. Under the description of each mineral, besides the ordinary physical characteristics, there is a note on its associations and occurrence. The use of cleavage in the classification seems to be helpful for the determination of those specimens which show good cleavage; but for those lacking cleavage, it is in some cases necessary to search through several sections before the mineral can be determined. For example, if a specimen of magnesite shows good cleavage, it can be identified readily in section 7; but if it happens to be of the white, massive, unglazed porcelain-like variety, it is not found in the section containing minerals with no cleavage, and search must be made through from one to three other sections to find it.

The method of classification adopted saves many pages, and if the principle is clearly understood, should result in little confusion.

D. J. F.

Fossil Plants, Volumes I–IV. By A. C. SEWARD. Cambridge: University Press, 1898–1919.

Seward's great textbook deals only with Thallophyta, Pteridophyta, and Gymnospermae. The printing is excellent, but there should be more illustrations. Each volume has an excellent index and an exhaustive bibliography. Since twenty-one years elapsed between the appearance of the first and the fourth volumes, there is naturally unevenness in the publication. While the last two volumes are up to date, the first two are somewhat antiquated.

This is now the standard textbook of the paleobotanist. The volumes deal not only with external structures, but also with the anatomic and morphologic features. In short, the book attempts to be a survey of our present knowledge of paleobotany. Every student of the subject will have to start from Seward, no matter what topic touching cryptogamic and gymnospermic plants he may approach.

A comparison with Schenk's *Handbuch* naturally forces itself upon the reader. There is no doubt that Seward's work is a great advance on Schenk's, although the latter is still an authority on fossil angiosperms.

If we compare the usefulness of Seward's book with, for instance, Zittel-Eastman's volume on Invertebrates, we cannot escape the conviction that Seward's book is not intended for determinations. There is still need for a handbook of paleobotany which can be used by the collector for determining fossil-plant genera and, if possible, species.

A. C. N.

Devonian Floras. By E. A. NEWELL ARBER. Cambridge: University Press, 1921.

The author lays down an essential distinction between the early and the later Devonian floras, and discusses the geological age and distribution of the two. The older is called the Psilophyton Flora, and the later, the Archaeopteris Flora, in accordance with the predominant plant types. Among the fossils of the Lower Devonian flora are the newly discovered types from Rhynie in Scotland which are at present the earliest known land plants.

Arber examines in detail the geologic age of different Devonian plant beds, taking into consideration only well-known floras of which the horizons have been more or less satisfactorily determined. He is inclined to accept a highly polyphyletic hypothesis with regard to the origin of the main groups of vascular cryptogams which he thinks to be derived severally from distinct algal types. He realizes that we are at a new point of departure in our knowledge of the evolution of higher plants, and his book is written from this point of view.

A. C. N.

A Catalogue of the Mesozoic and Cenozoic Plants of North America. By F. H. KNOWLTON. United States Geological Survey, Bulletin 696, Washington, 1919.

The book is a new edition of *A Catalogue of the Cretaceous and Tertiary Plants of North America*, much enlarged and supplemented. It includes the whole of the Mesozoic as well as the Cenozoic of North America, exclusive of Greenland and Mexico. The larger portion of the book is an alphabetical catalogue of plants to which is added a biologic classification of genera, an index of genera and families, and floral lists of plant-bearing formations. In his Introduction, Knowlton includes a table which gives the approximate stratigraphic position of plant-bearing beds, to which are added a few well-known non-plant-bearing marine units so that their relative positions may be seen.

The catalogue is one of the most useful books published on the North American fossil floras. A similar catalogue of the Paleozoic plants of North America is much to be desired. There is only one man who can write it—Dr. David White. Will he give it to us?

A. C. N.